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TEMPORAL ORGANIZATION OF RHYTHMIC UNITS IN NORMAL SPEAKERS AND STUTTERERS

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GEETHA KRISHNAN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **TEMPORAL ORGANIZATION OF RHYTHMIC UNITS IN NORMAL SPEAKERS AND STUTTERERS** submitted by **GEETHA KRISHNAN** in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE** in Speech Production and Perception.

To my mother and father

ABSTRACT

The rationale for the present study stems from the claims of the isochrony model and comb model of speech timing, that speakers of English maintain a certain temporal invariance within an interstress interval (rhythmic unit).

With reference to stutterers, it was questioned as to whether or not they would show similar temporal invariance, despite their timing disruptions at the laryngeal and the segmental levels. Moreover, it was also the intent of this study to obtain production data that will explain the perceptual differences between fluent speech of stutterers and normals. This investigation was in general designed to compare and characterize temporal organization of rhythmic units of varying sizes in stutterers and normal speakers of English.

The speech samples used in the analysis were obtained from the readings of two texts by nine normal speakers of English and stutterers. Rhythmic units varying in size from monosyllable to five syllables were extracted from these readings. Measurements of interstress interval, stressed vowel durations, unstressed vowel durations, and intervowel intervals were obtained by using segmentation procedures in a PDP-12A minicomputer.

The results showed no evidence of stress isochrony. Temporal compression and expansion of selected components were observed as a function of size of rhythmic unit. This provided evidence in support of the open loop (comb model) system for speech timing. Both stutterers and normals showed similar trends in temporal compression and expansion, with the exception of the longest unit. However, stutterers differed from normals in rate and extent of compression. Despite these differences, both groups had similar ratios between components of a given unit. The findings on temporal compression, expansion and relative timing are construed as language specific timing rules that operate to regulate rate and rhythm.

Relevance of these findings for the management and further understanding of stuttering are discussed. A possible model of speech timing is proposed to explain the temporal organization within rhythmic units in normal speakers. Finally, experiments are suggested for future investigations on rate and rhythm.

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I. INTRODUCTION

Investigations on the prosodic features of English grew with the efforts in developing speech recognition systems and synthetic speech. Lea (1976), for example, through a series of experiments demonstrated the value of prosodic information in speech recognition systems The prosodic features that convey linguistic information are intonation, stress, and rhythm. Of these, the latter two are intricately related in English. The rhythm of a language is more or less determined by the pattern of occurrence of events in time, whether it be articulatory units or pauses. For English, studies on the occurrence of stress in time would inevitably address the issues of rhythm and the temporal organization of speech in general.

The interstress interval which is also known as the metric foot or a rhythmic unit has been the focus of several investigations on the rhythmic structure of English. These studies will be reviewed in the next chapter.

There are three well known theories to explain temporal organization of rhythmic unit: the isochronous model, the comb model and the chain model. The isochronous and the comb models are open loop systems, and the chain model is a closed loop system. In the isochronous model, the interstress intervals are constant regardless of the number of intervening unstressed syllables. In the comb model, the speech segments are preplanned. This model is used to explain temporal compensations of segments and coarticulation. Lastly, the chain model hypothesizes that successive speech gestures are triggered by the completion of the previous one. The initiation of successive speech gestures will depend on the sensory feedback, an important factor in the closed loop model, not accounted for in the open loop systems

The rationale for the present investigation stems from claims made in the isochrony model and the comb model of speech organization that speakers of English tend to maintain invariance within a rhythmic unit.

As will be noted in the review in the following chapter, almost all the studies have concentrated their efforts in supporting or refuting the isochrony hypothesis. Besides, most of the earlier studies with the exception of a few (e.g., Shen and Peterson, 1962; Uldall, 1971, 1972, Lea, 1974) have based their conclusions on speech samples that are

produced under experimentally contrived conditions.

The present research was therefore undertaken to study temporal organization of rhythmic units in natural contexts such as within a discourse. In this study an attempt will be made to answer some of the questions with respect to the three well known models of speech organization. First of all, if stress isochrony exists in the natural flow of speech, is this isochrony determined by the very structure of the English language? Secondly, allowing for the fact that interstress intervals in English can range from a single syllable to several syllables, how do speakers maintain temporal invariance of rhythmic units? Do speakers maintain temporal invariance through adjustments in segment durations and or rate control?

If English speakers, on the other hand, preplan in terms of rhythmic units, then are there processing constraints that would determine the maximum length of a preplanned unit? Do these restrictions in processing somehow influence the structural make up of the language?

Lastly, if English speakers plan and produce speech in terms of syllables, then do stresses merely set the rhythm of the language by virtue of their acoustic prominence? Are there temporal regularities operating within an interstress interval that would determine the rhythm of speech? These are but some very basic questions we need to answer in order to understand temporal organization of speech.

With reference to stutterers, it is even more critical to understand how stutterers organize their speech temporally. Particularly, because stuttering is a temporal disruption in speech. Stutterers not only show disruptions at the segmental levels, timing lags have been observed at the laryngeal level as well, even during the production of fluent speech (e.g., Agnello and Wingate, 1971; Hand and Luper, 1980, etc. These and several other studies will be reviewed in the next chapter). Moreover, it has also been reported that stutterers' fluent speech is perceptibly distinct from that of normal speakers (e.g., Prosek and Runyan, 1982). One of the objectives of this study is to obtain production data that is likely to explain this perceptible difference between the fluent speech of stutterers and normals.

Several questions arise with respect to temporal organization of speech in stutterers. If the rhythm is set by the occurrence of stresses at equal intervals, as predicted by the isochrony hypothesis, then the question is whether stutterers, at least in

their fluent utterances, are able to follow a "normal" rhythmic pattern in their speech despite the laryngeal lags and asynchronies of the speech musculature? If some temporal invariance is the norm, then do stutterers strive to maintain this invariance through adjustments in rate and segmental durations?

On the other hand, if isochrony does not exist for normal speakers, but if English speakers tend to preplan their units in terms of interstress intervals, then do stutterers in their production of fluent utterances show any differences in their ability to preplan units of different durations? Would stutterers be closer to normals in preplanning smaller units than larger ones because of their production difficulties?

Lastly, would stutterers tend to use have abnormal pattern within rhythmic units, particularly because most therapy programs teach the strategy prolongation of syllables to facilitate fluency.

Besides understanding temporal organization of speech in stutterers, the inclusion of English speaking stutterers is likely to provide confirmation of certain normal trends about English. Despite several possible differences, stutterers may provide data consistent with that of normals' on certain aspects of temporal organization.

Although answers may not be found for all the above questions, an attempt will be made to answer several of them. This study is therefore, designed to characterize and compare temporal organization of rhythmic units in the fluent speech of stutterers and normal speakers of English.

In the next chapter, a review of temporal aspects of normal speech processes and temporal characteristics of fluent speech of stutterers will be presented. Specifically, the studies will cover issues on production and perception isochrony. Firstly, the various speech timing models, developed from studies on normal speech will be briefly described. Secondly, the studies on normal production and perception will be reviewed in the light of the the models of speech timing. On stuttering, firstly, production studies on timing will be reviewed, which will be followed by a review of perception studies on the fluent speech of stutterers.

The third chapter will be devoted to the methodology employed in this study. Information on subjects, nature and method of speech sample collection, instrumentation and the procedure used in obtaining durational measurements of speech samples will be

presented in detail.

In the fourth chapter, the results of several ANOVAs, other a posterori tests if any, and graphical illustrations for the various conditions will be presented and interpreted.

The fifth chapter will consist of discussions of the results. Further, implications for stuttering and for a speech timing model will be presented.

The sixth chapter will consist of conclusions of this study and implications for future research.

Following the final chapter, bibliography and appendices will be made available. The appendices will include the speech texts used in the primary experiment, the specially constructed sentences used in the auxiliary experiment, the computer programs used in obtaining durational measurements, statistical programs used in the analysis of the data, and the measurement data for all the components examined in this study.

II. REVIEW OF LITERATURE

Like most issues in speech research, the study of temporal organization of speech has been investigated through production and perception experiments. In this chapter, issues on temporal compensation in normal speech production and perception will be outlined. Following this review, research on temporal characteristics of fluent speech of stutterers will be presented. Some of the studies reviewed will include investigations on laryngeal timing, and perceptual differences in the speech of normals and stutterers.

A. Temporal Characteristics in Normals

In this section, the timing models of speech will be described. This will be followed by a review of research, the findings of which have a bearing on these models.

Timing Models of Speech

Since speech is temporally ordered, there have been several models of speech to explain timing. Lashley, in 1951, contradicted the associative chain theorists, in hypothesizing that speech production involves several interacting and interdependent systems, which he termed as "determining tendency". The determining tendency corresponded to the speaker's intentions. According to Lashley, the temporal ordering is not inherent in the idea, the word, or the motor organization, but it can control the ordering of the system. Syntax is considered a temporal ordering device, which integrates the idea, the word, and also ordering of the motor actions. Lashley's model is an open loop system in which several systems are constantly interacting.

Yet another open loop system is the Isochrony model. According to this model, stress syllables occur at equal time intervals in English, regardless of the number of intervening unstressed syllables, thereby, causing the compression of syllables in longer units. This model has been used to explain stress timing and its role in setting the rhythm in English.

Based on this assumption of stress isochrony, Martin (1972) proposed a model of speech rhythm, according to which, the timing of stressed and unstressed items are planned in a hierarchy. The stressed items receive primary emphasis and unstressed items

receive a secondary emphasis. The speech is decoded on the same basis by the listener. This hierarchy as opposed to concatenation allows for attention cycling between input and processing, whereas, perception of concatenated elements would seem to require continuous attention.

Kozhevnikov and Chistovich (1965) measured time within a syntagma in Russian. A syntagma is an articulatory sequence with no pause in between. It is sometimes one syllable and ranges up to seven. They concluded that the sucessive syllables within a syntagma are preplanned, and an articulatory unit of timing was a CV syllable. Kozhevnikov and Chistovich hypothesized an open loop model for the control of the syllable commands. They found that, within a syntagma, relative durations of syllables and words remained invariant within changes in rate, but relative durations of consonants and vowels within a syllable showed significant changes. That means compensatory changes in duration occurred at the segmental level in order to maintain invariance at the level of a syllable or in larger units. According to this model, successive syllables are preplanned and each syllable command is automatically initiated, by a rhythm generator in the nervous system.

In contrast to this model is the closed loop model, in which feedback plays a very important role. This model was first published by Fairbanks (1954). According to this model, the command for the next syllable is issued in response to an afferent impulse indicating the beginning of the preceding syllable.

Several researchers have concentrated their efforts to find empirical evidence for the above models. In the following section, some of the important investigations will be presented.

Rhythm in English

Any review of literature on the topic of rhythm will be incomplete without the mention of Pike's (1945) classification of languages as stress timed and syllable timed. Pike cited French and Spanish as examples of syllable timed languages in which syllables are more or less evenly spaced so that phrases with extra syllables take proportionately more time. In contrast to this, in stress timed languages like English, Pike observed that there is a tendency towards equal spacing of stresses. A single rhythmic unit is comprised of only one primary stress and varying numbers of unstressed syllables, but will have a constant

duration. This hypothesis is popularly known as the isochrony hypothesis. In sections to follow a rhythmic unit will be referred to also as a "metric foot" or a "foot", which is the time interval between two major stresses. The isochrony hypothesis suggests that the durations of segments within a rhythmic unit are altered depending on the number of unstressed syllables yet to be articulated within the foot, so as to maintain a certain constant interstress interval. Therefore, the production of syllables in the larger rhythmic units will undergo shortening, possibly vowel reductions and probably will also be articulated rapidly.

Although we have no evidence that Pike's speculations were based on experimental verifications, it is nevertheless an intriguing observation, based perhaps on his linguistic intuitions and personal observations. This hypothesis deserves experimental verification simply because speech process is not only a production process but a perceptual process as well, and the reality of linguistic intuition needs to be established.

Apart from these considerations, the import of Pike's isochrony hypothesis is that it proposes rhythmic unit as a unit of perception and/or production. Further implied in this theory is that segmental durations are affected by temporal constraints dictated by larger units (Port, 1980). In this context, Port refers to the interaction of temporal structures of two types, which he terms as the "temporal microstructure" and the "temporal macrostructure". The temporal microstructure reflects segmental durations such as inherent durations of phonetic segments. The temporal macrostructure determines timing over larger units, the size of syllables or larger (Nakatani, 1981). While the notion of inherent segmental durations is somewhat debatable, Port's dichotomy of temporal structures could nevertheless be utilized by redefining the microstructure to include timing feature rules at the segmental level such as Voice Onset Time (VOT) in addition to consonant and vowel durations. In dealing with the issue of rhythm in English we are directed to the temporal macrostructure.

Production Experiments

Absolute Isochrony:

Literally taken, experimental studies have so far shown no absolute isochrony. Many early researchers found no constant interstress intervals in their data (e.g., Shen and

Peterson, 1962; Bolinger, 1965, O'Connor, 1965). These researchers differed in the type of speech sample they studied and in their criteria for determining the primary stress.

Shen and Peterson (1962) obtained measurements between two "primary stresses" using prose samples read by three speakers. Each of them read a different passage. The investigators assumed that only one stress occurs in a sentence. They did not control for the length of sentences. Also, junctures between sentences were included in their interstress intervals. This resulted in a large variability when measurements were pooled for the three speakers. On the basis of these measurements Shen and Peterson rejected the isochrony hypothesis.

Bolinger (1965) used two lengthy sentences produced by six speakers. He measured the interval between accents that were first identified in the text. He found no evidence to support the notion of isochrony as 13 out of 53 intervals he measured were twice the length of the shortest interval. He also noted that, besides the number of syllables in an interval there were other factors such as syllable structure, nearness to initial or final positions and the relative semantic significance that influenced the length of an interval.

O'Connor (1965) analysed a limerick with a strict rhythm. The stresses were marked by clicks produced by hand. He then measured the distances between clicks. From these results O'Connor found no evidence in support of isochrony. In a later study, O'Connor (1968) examined the duration of foot in relation to the number of component sound segments. He made measurements on seven utterances using five speakers. Each of the utterances were made up of three monosyllablic feet. The second foot varied in segmental length from three to nine segments, while the first and the third foot remained constant. The durations of the variable foot increased as a function of segmental length. O'Connor found no evidence of temporal compensation in the variable foot.

In contrast to these findings, Uldall (1971, 1972) claimed isochrony for one speaker in a moderately slow "news reading" style. She analysed David Abercrombie's reading of "The North Wind and the Sun". The text was divided into rhythmic feet by the speaker. There were 56 metric feet in all and they ranged in duration from 260 ms to 870 ms. Despite this vast difference, Uldall claimed a tendency towards isochrony. The results showed that more than 57% of the filled feet (feet without pauses) fell between 385 ms

and 520 ms.The average durations of monosyllabic disyllabic and trisyllabic feet were 440 ms, 510 ms, and 540 ms, respectively. The average of the four-syllabic feet was, however, 760 ms, which differed greatly from the overall average of 520 ms.

Lehiste (1973) conducted production and perception experiments to verify yet another modification of the isochrony hypothesis. Abercrombie (1964,1965) claimed that metric feet (rhythmic feet) of different types are of equal durations. Lehiste constructed 17 sentences according to the rules established by Abercrombie. Each sentence consisted of four metric feet (e.g.,| Dīd thĕ | dôctôr | sāy | sômethîng |). The internal structure of each metric foot was made up of disyllables in which syllables differed quantitatively, i.e., short-long (⌣ —); medium-medium (⌢ ⌢); and long-short (— ⌣). Each of these foot types occurred in the four different positions in the test sentences. Syllable durations were measured from samples produced by two speakers. The results indicated that while similar durations were seen for feet of the same type, large variations in durations were noted for feet of different types. Therefore, Lehiste contended that production isochrony exists for feet of the same type.

Lea (1976) summarized his studies on rhythm and timing cues using sentences embedded in paragraphs. He reported that intervals between stresses are a linear function of the number of intervening stresses. Interstress intervals, however, tend to cluster near 0.4 seconds. Although this would be interpreted as a tendency towards isochrony, Lea argued that this tendency was perhaps due to the alternating stress-unstress pattern of English plus the somewhat uniform durations of unstressed syllable (For a detailed review of Lea's study see Lehiste, 1977).

Yet another recent study that failed to find support for the isochrony hypothesis was reported by Nakatani, O'Connor and Aston, (1981). This study was based on measurements obtained on reiterant speech produced by four speakers. In addition to studying stress position effects on syllable durations, Nakatani et al. probed the issue of stress isochrony. They studied foot durations as a function of foot size. That is, a one foot had one main stress which was marked by (1), and followed by an unstressed syllable denoted by (0). A two-foot (100), a three-foot (1000), and a four-foot (10000), likewise had two, three and four unstressed syllables following one main stress. The reiterant units corresponded to adjective – noun phrase configuration and these reiterant units were

embedded in a sentence. For example, "the *absurd day* made many ideas seem strange". was recorded as "the ma MAMA made many ideas seem strange". The nonsense syllables in small case had zero stress and those in Capitals had primary stress. Initially, several speakers (18) were selected and trained to produce fluent reiterant tokens. The subjects were at first required to say the actual English sentence, following which they were asked to produce the corresponding reiterant tokens. The speakers repeated the sentences with the reiterant units till the required stress pattern was produced. Measurements of syllable durations were then made from spectrograms Nakatani et al. acknowledged the unnaturalness of reiterant speech and cautioned that their results may not be reflective of rhythm in natural speech. They, nevertheless, claimed that their study showed "no evidence to support even a liberal interpretation of isochrony". In defence of this statement they noted that isochrony should be more evident in reiterant speech as the segmental variations are controlled.

Nakatani et al. also found phrase position effects on stress syllable duration for nouns but not for adjectives. Also for nouns, they noted that the phrase position effects on syllable duration other than the final position were negligible.

The results of this study also indicated that the overall word durations increased as a function of foot size They used these findings as further evidence to reject the isochrony hypothesis.

Thus far, absolute isochrony has not been reported. However, in several studies temporal compensations at the segmental level have been observed. It has been argued that the evidence of temporal compensation is indicative of rules that operate to maintain temporal invariance (Port, 1980). It is precisely this consideration that has led several others to argue in favor of the isochrony hypothesis.

Tendency towards Isochrony:

Several investigators have shown that syllables are longest in monosyllable words and decrease progressively as unstressed syllables are appended to the base words. (Lehiste, 1972; Lindblom, 1964; Lindblom and Rapp, 1973 ; Barnwell, 1971; Klatt, 1973; Rapp, 1971; and Huggins, 1975).

This conclusion has been drawn from studies based on a variety of speech samples. For example, Lindblom and Rapp (1973) in their study used nonsense words,

Lehiste (1972) used isolated words and short phrases, Barnwell (1971) used short phrases and Klatt (1973) embedded target words in carrier phrases. Rapp (1971) noted compensations between consonants and vowel durations in a word for Swedish samples.

Contrary to the findings on English in some of the aforementioned studies, Umeda (1972) found that the number of syllables in a word did not affect vowel durations. Owing this discrepancy to the nature of speech samples employed in earlier studies, Harris and Umeda (1974) hypothesized that temporal factors in isolated words, carrier phrases and connected text are governed by different rules. The apparent discrepancy, they said, must come from difference in speech mode and not from differences in speakers. They verified this formulation by examining the duration of stressed vowel (vowel as in "bat") as a function of number of syllables that followed. Two speakers produced the target words in carrier sentences and in connected speech. They found that results from both speakers were identical. They also noted that means for vowels in all non-prepausal positions were identical. There could be a number of reasons for this discrepancy between Harris and Umeda's findings and other studies. One possible explanation is that certain syntactic factors under certain conditions may induce temporal compensation. Huggins (1975) examined the combined effects of an appended unstressed syllable and the syntactic boundary on the duration of the preceding stressed syllable. In his classic example, "Cheese bound out", he observed that when an unstressed syllable was added to "cheese" (e.g., cheeses), there was a substantial shortening of the vowel in "cheese". However, when this unstressed syllable was added to an adjacent word (cheese abound), the vowel in "cheese" in fact increased in duration. However, when unstressed syllable was added to the word "bound", progressive shortening of the vowel was noticed regardless of whether the unstressed syllable was added within the word "bound" (bounded) or to the adjacent word (bound about). Huggins attributed this difference in the effect of unstressed syllables on "cheese" and "bound" to the occurrence of a syntactic boundary by which the subject "cheese" and predicate "bound" are demarcated.

Lea (1975,1976), acknowledging the effect of syntactic boundaries on the rhythmic structure of a metric foot, has noted that the mean interstress interval doubles when spanning clause boundaries and triples when spanning sentence boundaries. Interestingly, Lea also found that the mean pause durations that occurred between clause

and sentence boundaries tended to correspond to mean interstress interval. The pause durations between clause boundaries corresponded to one interstress interval, and the pause durations between sentence boundaries were twice the interstress interval. The increase in interstress interval as a consequence of clause and sentence boundary pauses is both adequate to signal the presence of syntactic boundary and necessary to disambiguate ambiguous sentences (Lehiste Olive, and Streeter, 1976) In an earlier study, Lehiste (1973) showed that the duration of the metric feet differed sharply for the two versions of an ambiguous sentence, although their internal rhythmic structures were identical. Disambiguation involves restructuring the sequences of a rhythmic unit by introducing a pause. Lehiste interpreted this as supporting the reality of metric feet as unit of production.

In a most recent paper, Dauer (1983) compared interstress intervals in continuous texts in English, Thai, Spanish, Italian and Greek. He found that interstress intervals in English which is supposedly a stress timed language is no more isochronous than interstress intervals in Spanish which is believed to be a syllable timed language. However, he noted that stresses showed a tendency to recur between 0.4 seconds and 0.5 seconds and this appeared to be a universal property. Dauer attributed this tendency towards isochrony to the fact that, in continuous text, interstress interval in English contains a maximum of five syllables, partly due to the syntactic nature of the language. Whereas, in Greek, Spanish, and Italian very rarely, there may be nine or ten syllables. Dauer further contended that the difference between stress timed and syllable timed languages lies in the differences in their lexical compositions, syllable structure, vowel reduction and phonetic realization of stress.

Several studies reviewed so far have based their arguments in favour of a weak version of isochrony hypothesis. This weak version of isochrony model is in fact referred to as the comb model, which suggests that intervals between stresses are preplanned but not necessarily equal.

Ohala (1975) has raised objections to studies that have showed negative correlations of durations between adjacent segments thereby demonstrating support of the comb model. Ohala attributed this negative correlations to the imprecise segmentation, speaking rate and size of the speech samples analysed. However, it appears that temporal

compensations observed by several researchers indeed occur and that it is not an inaccuracy resulting from segmentation procedures (Ellis and Weismer, 1978). In any event, Ohala argued for the consideration of both, the comb and the chain model in explaining the nature of speech planning. He postulates a hybrid model: the comb model to explain short term timing over a span of one or two syllables and the chain model to explain long term timing. Subsequently, evidence for both models has been demonstrated by Carlson and Granström, 1975. They found that under certain conditions where rhythmic demands were important, compensations were noted between consonants and vowels. However, perfect compensations never occurred. Carlson and Granström speculated that compromise is likely to occur if contradictory demands have to be met.

Lehiste (1973, 1976) continued to seek support for the notion of isochrony through production and perception experiments. In addition to syntactic constraints on production isochrony, Lehiste suggested the consideration of perceptual factors as well. This issue of perceptual isochrony will be the object of review in the following section.

Perception Experiments

Threshold for Duration:

Inspired by Classe's (1939) speculations, Lehiste (1973) reexamined the issue of isochrony. Classe's formulation suggested neither perfect production isochrony nor perfect perception isochrony, implying that speakers have a tendency to speak in rhythmic units that are perceived by listeners as isochronous (see Lehiste, 1977). In an earlier experiment, Lehiste (1973) attempted to test the perceptual reality of isochrony. Thirty listeners at first judged the durations of metric feet of 17 sentences and then of non speech stimuli which consisted of sequences of noise bursts and noise filled intervals corresponding to the rhythmic structure of sentences. The listeners' accuracy of judgements were better for non-speech stimuli than for metric feet in sentences. The conclusion of this experiment was that, if listeners cannot tell the differences of duration, then the rhythmic units are perhaps perceived as equal. If the observed durational change is less than one JND (Just Noticeable Difference), then it can have no little perceptual significance (Klatt, 1976).

English speakers have reported an unnatural timing pattern when a segment duration was changed by 20 ms (Huggins, 1972). In another study, while a minimum JND of 25ms was observed, JND increased by a factor of four under certain conditions (Klatt and Cooper, 1975). Thus, Klatt (1976) observed that durational changes of 20% or more may serve as primary perceptual cues for speech stimuli.

Lehiste (1977) in her review on isochrony argued that differences in durations of interstress intervals found in several studies (e.g., O'Connor, 1965; Lea, 1974; Lehiste, 1973) may actually be below the perceptual threshold.

Perception of Isochronous and Anisochronous Intervals

Another intriguing observation is that listeners perceive anisochronous intervals as isochronous. Coleman (1974) investigated isochrony within sentences that were controlled for grammatical and phonetic contexts (See Lehiste, 1977 for a review) The samples consisted of 16 real words and 16 nonsense words in carrier phrases. Each word consisted of two interstress intervals and each interstress interval contained zero to three unstressed syllables. He found that interstress intervals increased with increase in the number of syllables. However, listeners (40) tended to hear these anisochronous intervals as isochronous.

A similar finding is that listeners perceive isochronous intervals as anisochronous (Morton, Marcus and Frankish, 1976; Tuller and Fowler, 1981). Further, subjects made systematic changes to the acoustically isochronous intervals when they were required to adjust the interval until they were perceptually isochronous (Morton, Marcus and Frankish, 1976). To explain this, Morton et al. introduced the concept of a P–center which refers to the points of reference within a word which the listeners use to judge onset of the word. P–center is described as the "Psychological moment" of occurrence of a word. On further investigation, Morton et al found no correspondence of P–center to acoustically defined stress onset, word onset or vowel's peak intensity.

In two other related studies, Rapp (1971) and Allen (1972) investigated the location of stress beat in a word. Allen, in his study, used three subjects. Target sentences for experimental tasks were extracted from spontaneous conversations. The sentences were played repeatedly from a loop tape. Subjects performed three tasks. First, they tapped

their fingers "on the beat" for a specified syllable in a sentence. Second, they moved an audible click in the sentence until it coincided with the syllable beat for a designated syllable. Third, they judged whether or not an audible click that was superimposed on the sentence near a rhythmic beat "hit the beat". The subjects' location of "beats" on all the three tasks were in general agreement. The beats occurred in close proximity of the stressed vowels, their beats preceding the vowel's onset by a duration positively correlated with the length of the initial consonant clusters.

Rapp (1971) observed similar results with even higher correlations of beat locations to the duration of the initial consonants or consonant clusters. Subjects in this study repeated disyllabic nonsense utterance to the beat of a regularly occuring pulse. Although the subjects' production of disyllables corresponded with the pulse, the pulse preceded the stressed syllable by a duration that varied directly with the duration of the prevocalic consonant or consonant cluster.

This apparent similarity in findings of Rapp, Allen and Morton et al. that the occurrence of beat or P-centers show systematic departures from acoustic isochrony with no obvious corresponding acoustic correlates, led Fowler to propose that P-centers correspond to articulatory onsets. Fowler (1979) noted that when speakers were instructed to produce isochronous sequences, they produced acoustically anisochronous sequences, which listeners perceived as being isochronous. In other words this implies that our search for a correlate of isochrony should be at a different representational level other than the acoustic level.

Tuller and Fowler in a recent study (1980), used electromyographic recordings of orbicularis oris in five subjects to test whether perceptually isochronous sequences have isochronous articulatory correlates. Subjects were asked to produce alternating (duk,suk,... etc.) and homogeneous (bak, bak,...) sequence of sounds. In summary, the homogeneous sequences were acoustically isochronous. Alternating sequences were articulatorily isochronous, but showed departures from acoustic isochrony. That means the articulatory onset of certain consonants will not have obvious acoustical markers. This study, however, failed to find any correlate of P-center. Specifically, P-center was not found to correspond to articulatory onset of the initial consonant, the vowel or even the final consonant. In fact the articulatory onsets of the syllable's initial consonant consistently

occurred earlier than the P–center and the articulatory onset of the syllable's final consonant occurred consistently later than the P–center. Although Tuller and Fowler (1980) acknowledged the lack of evidence in this study for articulatory P–centers, they contemplated the possibility of the vowel's attainment of its target shape of the vocal tract (in MacNeilage, 1970) as a likely correlate of P–center. If an articulatory correlate were present for P–centers in natural speech as opposed to the contrived experimental conditions, it would indeed be a strong argument in favour of the motor theory of speech perception posited by Liberman, Cooper, Shankweiler and Studdert–Kennedy (1967). According to this model of speech perception, listeners use their own production experiences as a reference for perceiving speech sounds.

A motor basis for the perception of rhythm is, however, not a new notion. Abercrombie (1967) described speech rhythm as being "essentially a muscular rhythm" experienced as a rhythm of movement by both speakers and listeners sharing a common language and thereby a common experience of rhythm.

Summary

In summary, the rhythmic organization of English appears to be centered around primary stresses. Although absolute isochrony of interstress interval has so far not been reported, temporal compensations have been consistently observed. It is believed that temporal compensations would have long range effects if not blocked by syntactic boundaries. Perceptually, despite the variability in the interstress intervals that may result from changes in phonetic and grammatical contexts, listeners tend to perceive intervals as being isochronous. Two principal explanations have been offered to account for this phenomenon of perceptual isochrony. One, that the differences in duration are below the perceptual threshold. Second, the notion of P–centers and corresponding articulatory correlates such as isochronous onset of muscle activity have been suggested as the basis for the perception of isochrony. Apart from the controversial isochrony hypothesis, arguments in support of alternate models, the comb and the chain models, were presented.

In the rest of this chapter a review of the literature pertaining to temporal characteristics of fluent speech of stutterers will be presented.

B. Review on Stutterers' Fluent Speech

Fluency and disfluencies in the speech of stutterers are no longer considered as discrete events in the flow of speech but as points on a continuum (Williams, 1957; Adams and Runyan, 1981). Studies involving the analysis of fluent speech of stutterers are relatively few compared to the number of studies on stuttered speech. Basically these studies fall into three groups: One body of research has attempted to compare the clinically induced fluency of stutterers with the speech of normal speakers on different parameters, namely, acoustical and physiological. The second group of researchers have examined the laryngeal timing characteristics of stutterers. The third body of research has focused on perceptible differences between stutterers and normal speakers using a listener judgement paradigm.

Clinically Induced Fluency

Ever since Wingate (1969,1970, 1979) postulated the "vocalization" hypothesis to provide a consolidated explanation of the various fluency inducing conditions, several investigations have focused on acoustically characterizing the fluent speech produced under various therapeutic conditions. Some example of these conditions are singing, choral reading, rhythm, delayed auditory feedback (DAF), pacing, etc.

Reduction in disfluencies during singing is partially explained by increased utterance duration (Healey, Mallard, and Adams, 1976) and increased voicing duration (Colcord and Adams, 1979). Wingate (1976,1981), however, contended that reduced variation in intonation pattern in the singing and rhythm conditions causes shift in stress contrasts and changes in the prosodic pattern. Vowel length increases were also noticed during noise and rhythmic stimulation (Brayton and Conture, 1978) and under DAF (Novak, 1978). In addition, rate reduction and increased intensity resulted under DAF (Lechner, 1979) and when stutterers were asked to speak in high and low pitch (Ramig and Adams, 1981). Recently, Hayden, Adams, and Jordahl (1982) reported that shorter voice initiation times occurred during pacing. Voice initiation time was operationally defined as the amount of time that lapses between the onset of a stimulus and the subject's phonation. This, they explained was due to the effects of rhythm on timing control for onset of phonation.

Typically, under all these conditions, fluency is induced as a result of increase in duration of vocalization, reduced speaking rate, and increase in intensity. These acoustical changes, it is speculated, are the result of a series of aerodynamic variations (Adams and Hutchinson, 1974). Electromyographically, Freeman and Ushijima (1978) observed that lower levels of muscle activity and fewer instances of abductor-adductor cocontraction were associated with the four fluency evoking conditions, namely, choral reading, masking, DAF and rhythm.

Laryngeal Timing

The second set of studies, also triggered by the vocalization hypothesis, focuses on laryngeal timing in stutterers. The work on this topic has taken two major forms First, some studies have measured voice onset time (VOT) and voice termination time (VTT) in the fluent speech of stutterers. Voice onset time refers to the time that elapses between the release of a consonant and the moment of voicing. Voice termination time refers to the time that lapses between the end of a stimuli and the cessation of voicing. Second, some studies have used the reaction time paradigm to study laryngeal timing.

Investigating VOT and VTT in stutterers, Agnello and Wingate (1971) found that stutterers had longer termination times when compared to normals in the production of fluent CV syllables. Numerous other studies have showed that VOT of stutterers were longer than those of non stutterers in the production of fluent syllables (Agnello, Wingate and Wendell, 1974; Agnello, 1974; Hand and Luper, 1980). In on-going speech, Hillman and Gilbert (1977) observed greater lag in voicing in the fluent speech of stutterers than in normal speakers. Metz, Conture and Caruso (1979), in their investigation of VOT for frication and aspiration in the fluent speech of stutterers, found significant differences in VOT between stutterers and normals for some speech sounds only.

Reaction Time Studies

Several researchers have pursued to investigate vocal reaction time in stutterers on the basis that a phonatory lag would result from a delay and difficulty in coordinating the speech mechanism in producing voice. Most of the researchers have employed reaction time techniques requiring stutterers to produce voice or speech when a signal is

presented.

Venkatagiri (1981) obtained reaction times for initiation of whispered /a/ and voiced /a/. The results showed that stutterers took longer time for initiating a voiced /a/ compared to a whispered /a/. Reaction times for normals did not differ for the two tasks. When the two groups were compared, however, statistically significant differences were not found between normals and stutterers for both the tasks. This finding contradicts several earlier findings.

Adams and Hayden (1976), Cross, Shadden and Luper (1979) and Cross and Luper (1979), obtained response latencies for the production of isolated vowels in response to a pure tone signal. They found that stutterers were slower than normals in vocally responding to the signal. Other researchers asked their stutterers to produce a syllable in response to a flash of light (Starkweather, Hirschman and Tannenbaum, 1976) and some others asked their subjects to produce a VC syllable in response to visual and tone signals.

In addition to vocal reaction times, Prosek, Montgomery, Walden and Schwartz (1979) obtained manual reaction times. They found that while stutterers' reaction times for the production of VC syllables were slower, their manual reaction times as measured by EMG, did not differ from normal speakers. Consistent with this, Reich, Till and Goldsmith (1981) found that stutterers and normals differed significantly on speech phonation tasks. The difference for throat clearing approached significance, but the two groups did not show significant differences on the finger tapping task.

In another study, McFarlene and Prins (1978) used EMG activity in orbicularis oris as a measure of reaction times for producing syllables to auditory and visual stimuli. They found that stutterers were significantly slower than normals in response to auditory signal, but they did not differ significantly in their response to visual signals. Recently, however, McFarlene and Shipley (1981) examined whether or not stutterers and normals differed in latency of vocalization onset for auditory and visual stimuli. They found that while stutterers were slower than normals on nearly all measures in the study, overall differences were not significant across stimulus modes and response conditions.

The inconsistency in findings noted in the literature on reaction times may be due to methodological differences such as practice effect or due to the severity of stuttering in the population used in the studies.

Apart from these timing delays in initiating voicing and terminating phonation, stutterers' fluent speech have also been found to have longer vowel durations and longer transition times (Adams, Runyan and Mallard, 1975; Disimoni, 1974; Starkweather and Myers, 1979; Hand and Luper, 1980; and Kerr and Cooper, 1976). Transition time refers to the time taken for the articulators to move from a consonant to a vowel.

Cooper and Allen (1977) assessed the timing control accuracy of ten normal speakers and five stutterers on a variety of tasks such as sentence repetitions, paragraphs, and nursery rhymes. A finger tapping task was used as a control task. They found that on most experimental tasks normal speakers were more accurate timers than stutterers. They discussed the results in terms of timing control processes such as a neural clock for controlling speech segment durations and a speech motor output buffer whose capacity may be limited in stutterers.

Additionally, direct evidence of lags and asynchronies has been reported by Zimmerman (1980) using high speed cineradiography. Zimmerman studied movements, positions and timing of lip and jaw structures during the production of fluent syllables of /pap/, /mam/, and /bab/. He found that movement onsets had longer onsets and consequently the VOT were slower for stutterers. Stutterers also took longer time to attain peak velocities of lip and jaw structures. They held their postures longer and transition times were longer as well. In addition, stutterers showed asynchrony between lip and jaw movements.

In another study, Shapiro (1980) reported on an EMG analysis of fluent and disfluent utterances of several types of stutterers. Shapiro found that inappropriate and excessive muscular activity was present during the production of fluent and disfluent utterances for stutterers.

All these studies mentioned above differentiate the fluency of stutterers from that of normal speakers, both in the process of production and in their acoustical representations. Therefore, it seems reasonable to expect stutterers' fluency to be perceptibly different from the fluency of normal speakers.

Perception Studies

Typically, to study perceptible differences between speech of stutterers and that of normals, the listeners were asked to identify the stutterers' utterance from a pair, one of which was a fluent utterance from a normal subject and the other was spoken by a stutterer. Listeners successfully identified stutterers from normals from the fluent samples (Wendahl and Cole, 1961; Few and Lingwall, 1972; Hotchkiss, 1973; Runyan and Adams, 1978, 1979; Critcher, 1979 and Prosek and Runyan, 1982). Further in some studies, listeners were asked to indicate the basis on which they differentiated a stutterer's fluent utterance from a normal speaker's. Listeners have indicated use of a variety of cues. However, Adams and Runyan (1981) have grouped these cues into five categories: rate, rhythm, effort, laryngeal behaviour and articulation. Rate includes listeners' subjective judgements such as, poor speaking rate, slower rate, longer syllable durations and abnormal rate. Rhythm includes "less normal rhythm", abnormal pauses and hesitations. Effort refers to low vocal intensity. Laryngeal behaviour includes laryngeal tension and vocal tremor. Articulation refers to imprecise articulation.

Recently, Prosek and Runyan (1982) reported correlations between certain temporal measurements to listener judgements. From fluent speech samples of 35 stutterers and 35 non stutterers, they obtained averages of speaking rate, number of pauses, pause duration and duration of stressed vowels. These averages were then correlated with listener judgements. The results showed that speaking rate and pauses were important for the listeners in differentiating stutterers' speech from normals'. However, as Prosek and Runyan themselves point out, the choice of predictors in the multiple regression analysis they used could have very well influenced their results.

Summary

In summary, the acoustical, physiological and the perceptual characteristics of stutterers' fluency show marked differences across several related temporal factors such as phonatory onset, segmental duration, and speaking rate. Mention has been made of rhythm in the literature. "Abnormal rhythm" is one of the distinguishing features of stutterers' fluency. It is often used with reference to abnormal pauses or hesitations, syllable tapping, talking to the beat of a metronome etc. Here, in the literature on stuttering,

the term "rhythm" is used in a general sense to describe events in the flow of speech or successive events at set intervals. In the present study, however, rhythm is defined linguistically. A rhythmic unit, is synonymous with the metric feet and the interstress interval. Basically, this interval is comprised of stress vowel duration, unstressed vowel durations and intervowel intervals.

For the purposes of this study, the question of interest is whether or not stutterers follow language specific temporal rules of rhythmic units in their fluent productions despite timing disruptions at the laryngeal and segmental levels. The prediction is that if stutterers attempt to maintain temporal relations in larger units as specified by the language, then adjustments in speaking rate are likely to occur to compensate for slow onsets and delays.

III. METHOD

This chapter provides a description of the procedures involved in obtaining speech samples and subsequently the measurement data from the samples.

A. Subjects

Speech samples were obtained from twenty male subjects, ten normal speakers and ten stutterers. Both groups of speakers were native speakers of Canadian English. Eight stutterers had undergone group treatment a year prior to this recording. However, their stuttering had relapsed overtime, which subjectively placed them in a moderate-severe range. These eight stutterers were recorded prior to their commencement in a refresher therapeutic program. Two other stutterers reported having had no prior treatment. They were both judged to be in the moderate-severe range as well.

The samples of these subjects were selected from 29 subjects who were initially recorded. All the subjects were required to produce all the target items fluently. Speech samples from two female stutterers were obtained, but were excluded from the study as they were not fluent on several of the target items Since there were no other female stutterers who were available at the time of recording only male speakers were used for the normal group.

B. Materials

The subjects were required to read two passages. One was a passage extracted from an article in Scientific American, and the other one was a dialogue from a radio play (Appendix I). These two texts were used because the intent was to study temporal organization in connected speech in a natural context The two different texts offered possibilities for the natural occurrence of the different foot sizes. Both these passages consisted of rhythmic units ranging from monosyllable stress units to five-syllable units.

Only two levels of stress were considered since perceptually two levels of stresses, stressed and unstressed seem to be relevant (Nakatani, et al., 1981). The primary stresses are numerically denoted by 1 and unstressed syllables are indicated by 0. Lexical stresses were marked by two linguists and the agreement was almost perfect. One particular word that received different stress markings from the two linguists was not part of any of the target rhythmic units.

The various foot sizes are synonymously referred to as rhythmic units and interstress intervals. The descriptions of the various foot sizes used were as follows: monosyllabic rhythmic unit or foot also known as F1 consists of one stressed vowel. The number refers to the number of syllables in the foot F. A disyllable rhythmic unit or foot, known as F2 consists of one primary stressed vowel followed by one unstressed syllable. Likewise, F3, F4, F5 and refer to three syllable, four syllable and five syllable feet or rhythmic units.

The rhythmic units spanned over word boundaries. Both content and function words were included in these units. The word boundaries were intentionally included within the interstress intervals in order to overcome the limitations of some earlier investigations as acknowledged by Nakatani et al., (1981) in their study. Since utterance final position have been found to increase duration of vowels (Flege and Brown, 1982), rhythmic units consisting of clause boundaries were excluded. It is also well known that speakers introduce a pause equal to an interstress interval as clause markers and twice the interstress interval to mark sentence boundaries (Lea, 1975, 1976).

All the utterances that were available for the different foot sizes were not used in the analysis. Tokens were selected following a pilot segmentation on the basis of ease of segmentation. Some tokens were excluded because several subjects did not successfully produce those items Thus, by a process of subject and token elimination, four tokens were chosen for each of the foot sizes, F1, F2, F3, and F4. Although some F5 units were available from the narrative passage, measurements were obtained on only one token. Other available tokens were eliminated for reasons mentioned earlier. Further two subjects, one normal speaker and one stutterer were excluded following the initial ANOVA. These subjects were found to be outliers. The data presented and discussed are based on measurements obtained on 9 normal speakers and 9 stutterers. In addition, one

token in F3 had to be removed from all statistical analyses. Thus, measurements made on four tokens for each of F1, F2, and F4 were used in the statistical analyses. For F3, data on three tokens were used in the statistical analyses. In some analysis of variance (ANOVA) one token for F5 was included in the analysis.

C. Auxiliary Experiment

In addition to the principal experiment, an auxiliary experiment was done in which five normal speakers were asked to read sentences in which rhythmic units were embedded in specially constructed sentences (RUSS, Appendix I). This experiment was done to obtain baseline data on normal speakers, particularly for the six syllable units (F6) as these units were not available in the texts chosen for the primary experiment. Rhythmic units in RUSS ranged from F1 to F6. Measurements on these samples were obtained using the same procedures that were used in the principal experiment.

D. Apparatus

The instruments listed below were used in this study. Wherever relevant, the technical specifications of these instruments accompany the listing.

Microphone: Sennheiser MD 421 N

-frequency response: 30-17000 Hz $\pm$ 5 dB.

-sensitivity: 0.2 mv/microbar at 1000 Hz

-directionality: cardoid

Tape recorder: TEAC A 7030 GSL

-frequency response: $\pm$ 2 dB, 50-15000 Hz

-speed: 7.5 ips.

-SNR: 58 dB.

Audio frequency filter: Rockland Programmable Dual Hi/Lo filter, series 1520
-frequency range: 0.001 Hz to 111 kHz
-accuracy: $\pm$ 2% of dial setting.

Oscillator: Hewlett-Packard 204 D

Graph plotter: Hewlett-Packard 7001, AMR X-Y recorder

Minicomputer: PDP-12 A
-memory: 16 Kbits.
-operating systems: OS/8 and Alligator.

E. Recording

Subjects were individually recorded in a sound treated recording room. In order to eliminate cross talk effects, only one channel (left) of the TEAC was used. Each subject was instructed to read the two passages in any preferred order. No mention was made of the rate of speech or the accuracy of production of the target items The intent of the experiment was not known to the subjects. Only one reading was obtained from each of the subjects.

F. Sampling

The acoustic data was sampled by the computer for digitization and subsequent storage. The selected stimuli were digitized at a 16 kHz sampling rate on a PDP-12A minicomputer using Alligator operating system (Stevenson and Stephens, 1978). The audio signal was first passed through a band pass filter set from 68 Hz to 6800 Hz to eliminate 60 Hz noise and prevent aliasing. The calibration of the amplitude of the signal prior to sampling was made to prevent peak clipping. Signal clipping was prevented by adjusting the amplitude of the signal at the source. Following this calibration, the signal was transferred to the computer, digitized and stored in the computer memory.

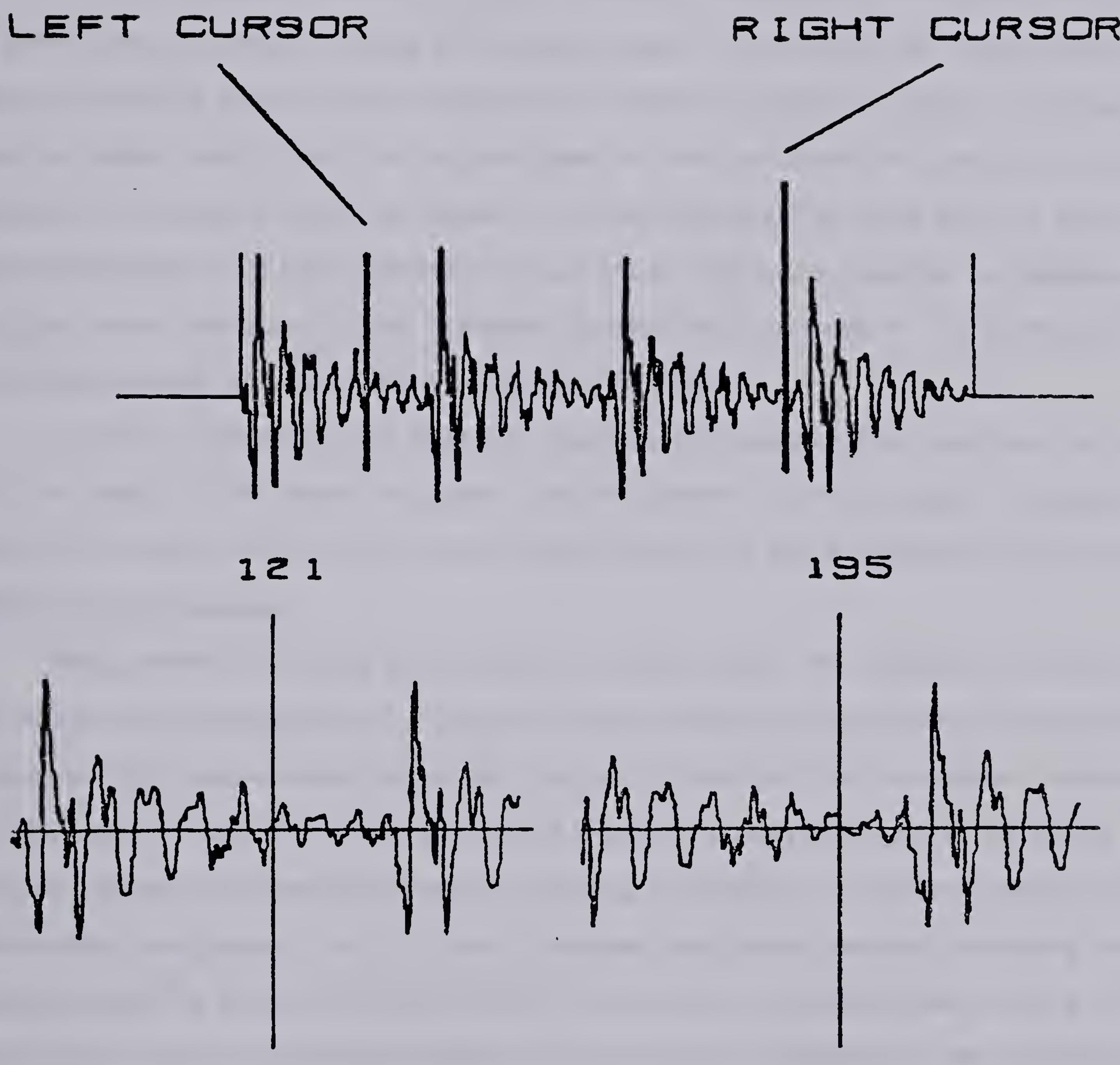


Figure 3.1 Editor display. The top trace is the signal being edited and the bottom two traces are 'edit windows' giving magnified views of the signal surrounding the left and right cursors (Stephens & Stevens, 1978).

G. Segmentation and Measurements

The signal was retrieved using a program (Appendix II) which automatically displayed 1.6 seconds of the signal. Auditory playback was available which aided the segmentation process. Another sub program allowed the editing of the signal.

The editor display is shown in Fig. 3.1. A single trace appears in the upper half of the screen and two shorter traces of the signal appear in the lower half. These shorter traces are referred to as the "edit windows" and display the region of signal 120 sample points on either side of the two cursors seen on the top trace. The cursors can be positioned at any point along the signal by potentiometers. The program also allows auditory playback of the signal between the cursors and the entire signal can be displayed. The signal within the cursors was extracted, labelled and the duration of the extracted portion automatically measured and printed on the teletype.

For each rhythmic unit, the stressed vowel, the unstressed vowels, and the interval from the onset of one vowel to another until the interval from the onset of stressed vowel to the onset of the next stressed vowel known as. the interstress interval was segmented and measured.

Measurement of vowels were made from their onsets. The beginning of a vowel was defined by the emergence of a complex periodic waveform appropriate to the vowel in question. The cursors were placed near the zero crossings of the waveforms before the major peak. Decisions were based on both visual and audio play back. Fig. 3.2 shows a computer display of the sampled waveform showing a disyllable unit. The time markers are alphabetically designated, A to E. A and B indicate the cursor markings enclosing the stressed vowel. The onset of stressed vowel to the onset of first unstressed vowel is AC, the duration of the first unstressed vowel is CD, the interval from onset of the unstressed vowel to the onset of the next stressed vowel is CE. This completes the entire interstress interval which is defined as the duration from the onset of the stressed vowel to the onset of next stressed vowel. By adding the durations of the segments AC + CE the interstress interval of the rhythmic unit can be computed. The intervowel intervals were also calculated by simple arithmatical method. For example, the intervowel interval, BC = AC − AB.

Figure 3.2 Sampled speech waveform showing components of a disyllable unit.

It should be noted that some arbitrary decisions had to be made whenever segmentation was difficult as in instances where vowels were followed by l or r. The audio play back of individual segments greatly aided in the segmentation, particularly in the segmentation of vowels bounded by nasals.

IV. RESULTS

In this chapter the results of five analyses of variance (ANOVA) on five components of the rhythmic units will be presented. The five components are: the interstress interval (ISI), the stress vowel (SV), the first unstressed vowel (1USV), the total unstressed vowel (TUSV), and the intervowel intervals (IVI). The analysis of variance was carried out using BMDP statistical programs Also presented are results of a posteriori tests, namely, the Tukey A test for comparisons of pairs of means and trend analysis on some of the components. Further, some of the significant interactions will be examined through graphical illustrations.

At first ANOVA was done for the ISI using ten subjects in each group and 4 tokens for each foot size. However, further examination of the subject means showed one subject in the stutterers' group as an outlier. In addition, one of the tokens for F3 showed mean durations that were large enough to have contained a pause in the rhythmic unit. Therefore, this token was eliminated from further analysis for all the subjects. The mean duration value for F3 was used in the place of the missing value. Further analyses were carried out using 9 subjects in each group.

In addition to the results on the principal experiment, data on 5 normal speakers from the auxiliary experiment will be presented. In this auxiliary experiment, rhythmic units were embedded in specially constructed sentences. The segments from this experiment will be referred to as rhythmic units in special sentences (RUSS).

A. Interstress Interval (ISI)

For interstress interval, a mixed factorial ANOVA was carried out. The results presented here are from the analysis that was done for nine subjects in each group on foot sizes, F1, F2, F3, and F4. With the exception of F3, all the other foot sizes had 4 tokens. F3 had 3 tokens. The mean value of these three tokens were used in place of the missing value for F3. The five syllable foot size was not included in this ANOVA, but the value for a single token under F5 was used in the graphical illustration.

The results of ANOVA (summarized in Table 4.1) showed that both stutterers and normals had significant differences in means for foot sizes ($F=153.96$, $df=3$, $p<0.001$).

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(G)	58734735.	1	58734734.7	988.57	0.0000
G	S(G)	944625.	1	944625.1	15.90	0.0011
F	SF(G)	5679210.	3	1893070.0	153.96	0.0000
S(G)	T(GSF)	950619.	16	59413.7	6.63	0.0
GF	SF(G)	252301.	3	84100.4	6.84	0.0006
SF(G)	T(GSF)	590203.	48	12295.9	1.37	0.0676
T(GSF)		1935107.	216	8958.8		

Table 4.1 ANOVA summary for interstress intervals.

The durations of ISI increased as a function of foot size for both groups.

Significant differences were also noted for group means ($F=15.90$, $df=1$, $p< 0.001$); stutterers showing significantly greater means when compared to normals. This differences between stutterers and normals increased with increase in foot size. This is demonstrated by the statistically significant F value obtained for foot size by group type interaction ($F=6.84$; $df=3$, $p< 0.0006$). These results are graphically illustrated in Fig. 4.1. Most importantly, ISI increased as a function of foot size for both the groups due to the mere increase in number of syllables. However, the plot for both the groups fall below the linear extrapolation, which is indicated by split lines, suggesting some degree of temporal compression. For stutterers, at F5, the curve lies above the dotted curve, showing greater than linear increase. When this data was subjected to a trend analysis, a significant linear trend was found ($F_{lin}=4.73$ at 0.05 level. See Table 4.2).

Figure 4.1 also shows that the ratio of stutterer to normal duration increases with increase in foot size. Compared to normals, stutterers' mean duration for F1 is greater by 16%; for F2, 24% for F3, 29%; for F4, 36%; and for F5 by 44%. Qualitatively, this progressive increase in differences between the two groups is noted in the widening of the gaps between the plots for stutterers and normals as a function of foot size (Fig.4.1).

Additionally the Tukey A test was done to test the significance of the differences between pairs of means.

In Table 4.3 the Q values are tabulated. Normals showed significant differences between F1 and F3 ($Q=5.03$, $p<0.01$); and F1 and F4 ($Q=8.34$, $p<0.01$). Stutterers showed significant differences between F1 and F2 ($Q=4.78$, $p<0.05$); F1 and F3 ($Q=7.43$, $p<0.01$); F1 and F4 ($Q=12.72$, $p< 0.01$) and F3 and F4 ($Q=5.29$, $p<0.05$). The results tabulated in Table 4.3 also shows significant differences between other pairs of means that contributed to the overall significant F for the foot size by group type interaction.

The ISI offers a dependable measure of speech rate. Time per syllable rates were calculated for the different foot sizes. Fig. 4.2 illustrates change in rate in terms of time taken per syllable, as a function of foot size, for stutterers and normal speakers. Stutterers and normals take increasingly less time to articulate a syllable as a function of foot size. Normal speakers on the average take approximately 239ms per syllable for a monosyllable foot, 182ms per syllable for a disyllable foot, 141ms per syllable for

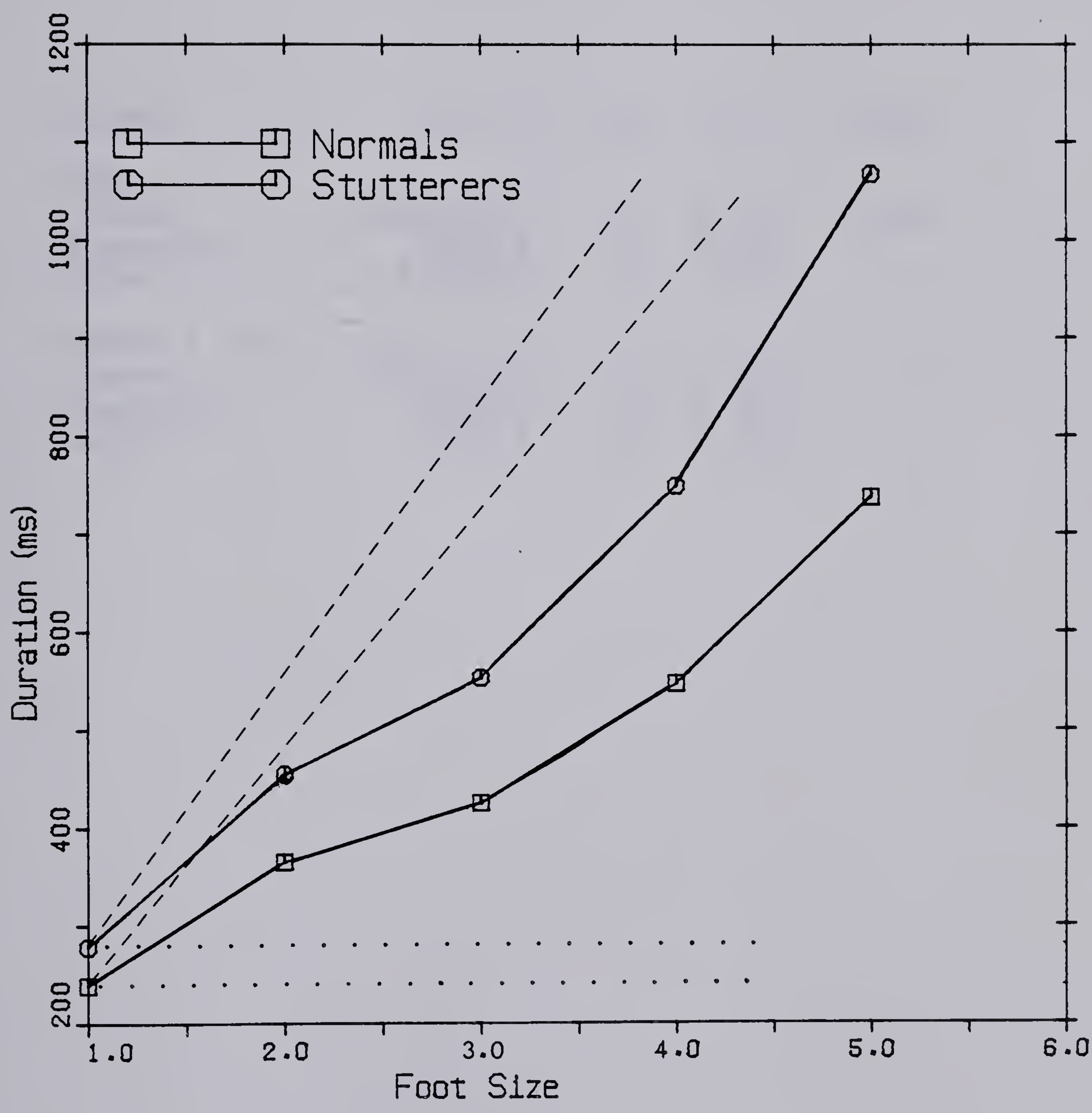


Figure 4.1 Interstress interval as a function of foot size.

SOURCE	SS	df	F	PROB
FOOT				
Linear	5594292.1	1	4.73	0.05
Quadratic	924.5	1	0.04	
Cubic	83692.0	1	1.52	
GROUP x FOOT				
Linear	247642.7	1	0.20	
Quadratic	2532.3	1	0.10	
Cubic	2073.6	1	0.03	

Table 4.2 Summary of trend analysis for interstress intervals.

F=FOOT SIZE   N=NORM   S=STUTT

	F1N	F1S	F2N	F3N	F2S	F4N	F3S	F4S
MEANS	239.0	278.4	365.5	425.4	455.1	547.2	553.1	748.8
F1N		1.06	3.42	5.03**	5.84*	8.34**	8.50**	13.79**
F1S			2.36	3.97*	4.78*	7.27**	7.43**	12.72**
F2N				1.61	2.42	4.92*	5.08*	10.37**
F3N					0.80	3.30	3.46	8.76**
F2S						2.49	2.65	7.94**
F4N							0.16	5.45**
F3S								5.29*
F4S								

* P<0.05   ** P<0.01

Table 4.3 Results of Tukey A test for interstress interval.

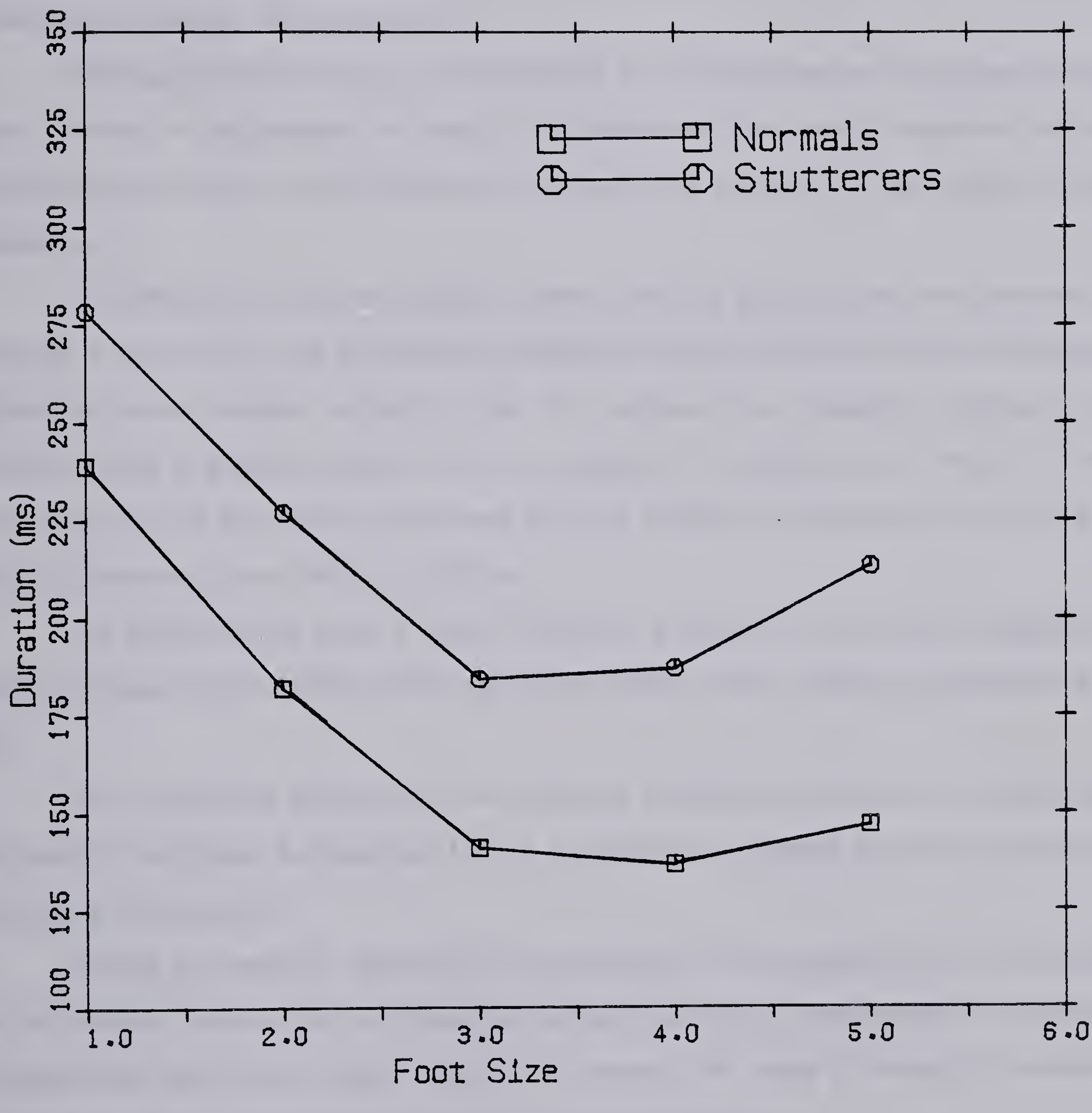


Figure 4.2 Time taken per syllable as a function of foot size.

trisyllable, 136.8ms per syllable for four syllable, and 147ms per syllable for a five syllable foot. Stutterers, on the other hand, require approximately 278ms per syllable, 227ms per syllable, 184.3ms per syllable, 187.1ms per syllable and 213.4ms per syllable for monosyllable, disyllable, three syllable, four syllable, and five syllable foot, respectively. Thus, both stutterers and normals show rate increase as a function of foot size for three or less syllables. For the four syllable unit, the rate shows stabilization. This is followed by a decrease in rate for the longest unit.

Although stutterers follow a trend similar to normals, they are consistently slower than normals. A progressive increase in the difference for rate is observed between stutterers and normals. Their difference in rate being the greatest for the longest unit (five syllable unit).

A significant F value for subject nested within the group factor was obtained ($F = 6.63$, $df = 16$, $p < .01$). This is graphically illustrated in Fig. 4.3a,b in the form of histograms Stutterers show greater variability than the normals. The frequency distribution for stutterers has a greater spread than for normals. For stutterers, the range of means averaged over all foot sizes is between 421 ms to 643 ms, whereas, for normals the range is narrower from 348 ms to 455 ms.

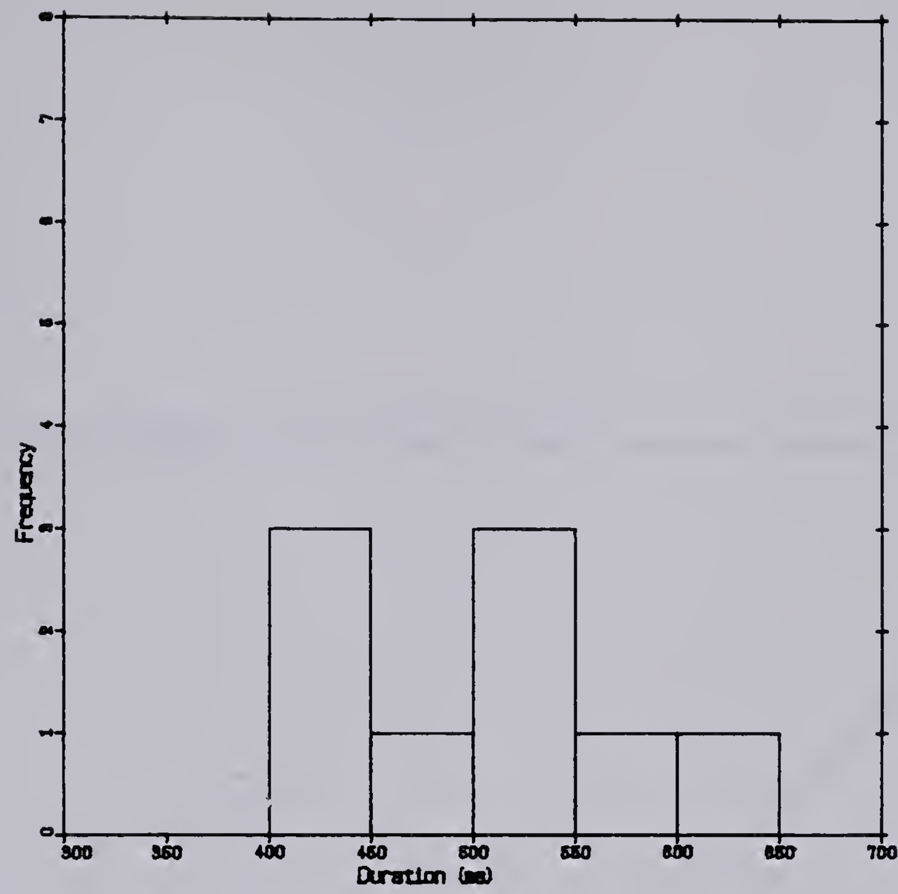
For RUSS, the ISI show a linear increase as a function of foot size, suggesting an almost constant rate in terms of time taken per syllable. These results are illustrated in Fig. 4.4.

Since both the primary and the auxiliary experiments showed no evidence of production isochrony, the data was further examined for possible evidence in support of isochrony in perception.

Firstly, the range of means from monosyllable to five syllable foot was observed to fall relatively within a narrow range for normals (239 ms to 748 ms)than for stutterers. Despite their significantly longer interstress intervals, the range of means for stutterers was 0.2 seconds to 1.06 seconds from F1 to F5 syllable foot.

Secondly, a frequency count of the different foot sizes was done on the two texts that were used in this study. Table 4.4 shows that the disyllable foot occurred most frequently in both the texts.

a



b

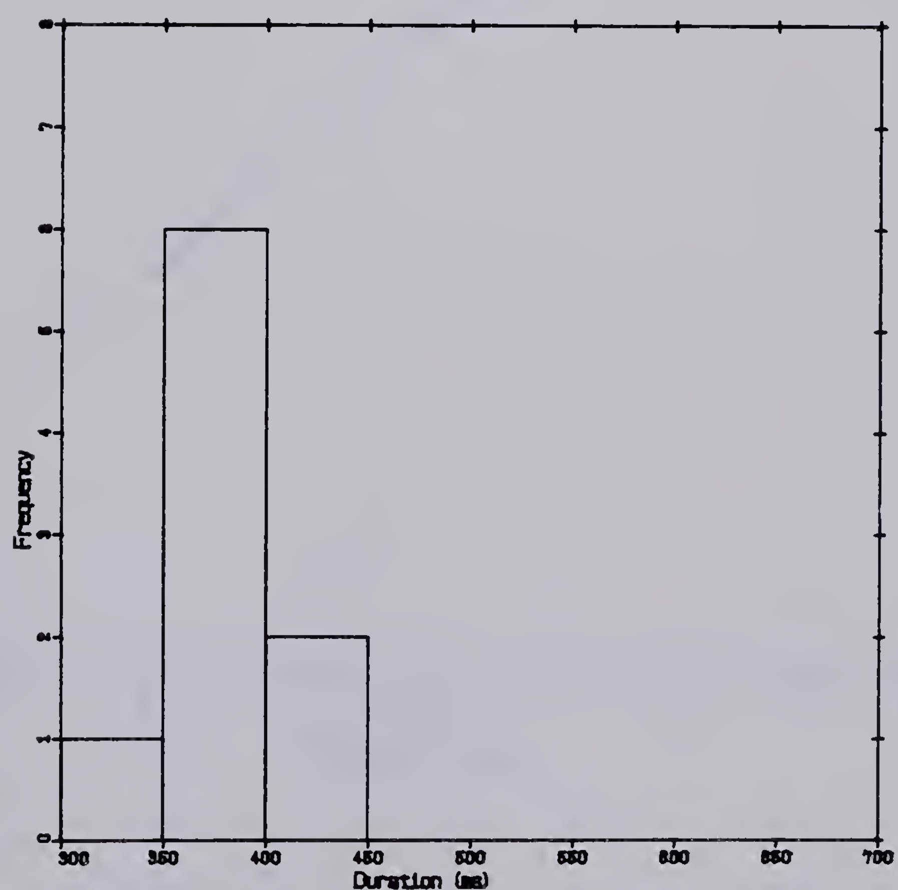


Figure 4.3 Frequency distribution of interstress intervals: (a) Stutterers (b) Normals.

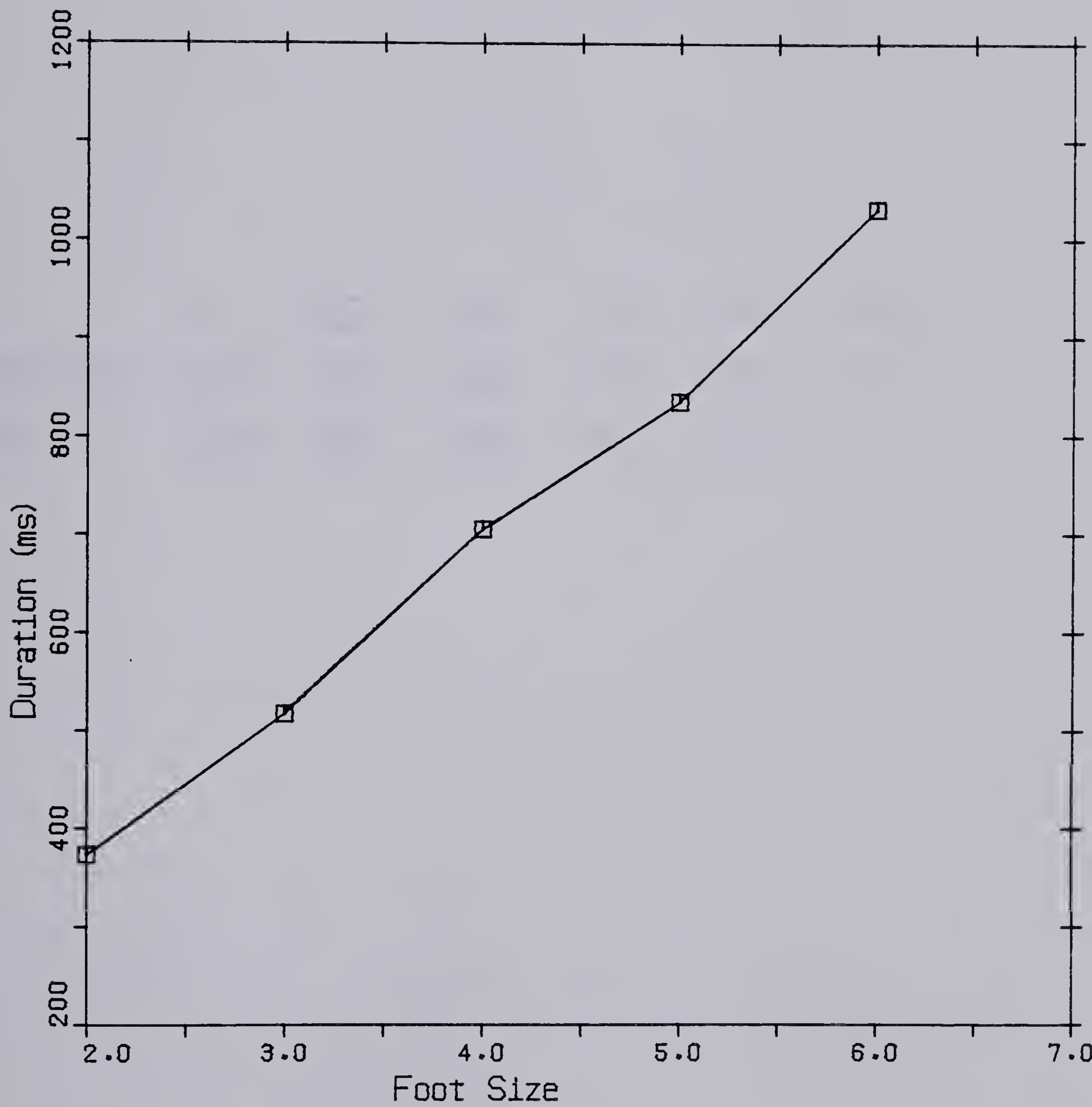


Figure 4.4 Interstress interval as a function of foot size for RUSS.

	F1	F2	F3	F4	F5	F6
NARRATIVE	22%	41%	20%	8%	6%	3%
PLAY	21%	45%	25%	6%	3%	

Table 4.4 Frequency count of foot sizes in the two texts.

Thus, both the measured interval range within which stresses occur and the frequent occurrence of disyllable foot in English could partly explain why speakers of English perceive stresses as occuring at isochronous intervals.

B. Stressed Vowel Duration (SV)

The results of the ANOVA for stressed vowel durations are summarized in Table 4.5. Measurements on four tokens each for F1, F2, and F4; three tokens for F3 and one token for F5 were used in this ANOVA.

The results showed significant differences in the mean durations for foot size ($F=39.79$, $df=4$, $p<0.001$). The results also showed significant differences for subjects nested within group factor ($F=3.20$, $df=16$, $p<0.001$). Fig. 4.5 is a graphical illustration of duration of stressed vowels as a function of foot size. This figure shows that the mean duration of stressed vowels is shorter in a disyllabic rhythmic unit than in a monosyllabic unit. Following a slight increase in duration for F3, the mean durations of stressed vowels progressively decreases for F4 and F5. Thus, the stressed vowel duration for stutterers and normals in general, showed temporal compression as a function of foot size. A trend analysis (Table 4.6) on this data showed a significant linear trend at the 0.001 level and a significant cubic trend at the 0.01 level. Tukey A test was performed to identify the pairs of means that contributed to a significant F value for foot size. The results tabulated in Table 4.7 show statistically significant difference betweeen F1 and F5 for normals ($Q=5.31$, $p<0.01$) and for stutterers ($Q=5.36$, $p<0.01$). For stutterers, in addition, the difference between F3 and F5 was significant ($F=5.31$; $p<0.05$). Fig. 4.5 also shows that the ratio of stutterer duration to normal duration for any given foot size does not appear to be significantly large. This observation is statistically confirmed by the results of the ANOVA (Table 4.5) which showed that the group means and the group type by foot size interactions were not statistically significant.

Thus, both stutterers and normals showed a similar trend in the temporal compression of stressed vowel as a function of foot size. However, when compared to normals, the absolute mean durations for stutterers were greater, the extent of compression seen from monosyllabic unit to the five syllable unit was greater for normals than for stutterers. While normals showed a compression of about 38.3% from

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(G)	3958297.2	1	3958297.22	928.59	0.0000
G	S(G)	27092.0	1	27092.02	6.36	0.0227
F	SF(G)	103587.4	4	25896.85	39.79	0.0000
S(G)	T(GSF)	68203.0	16	4262.69	3.20	0.0000
GF	SF(G)	2332.5	4	583.12	0.90	0.4716
SF(G)	T(GSF)	41649.1	64	650.77	0.49	0.9996
T(GSF)		359291.7	270	1330.71		

Table 4.5 ANOVA summary for stressed vowel.

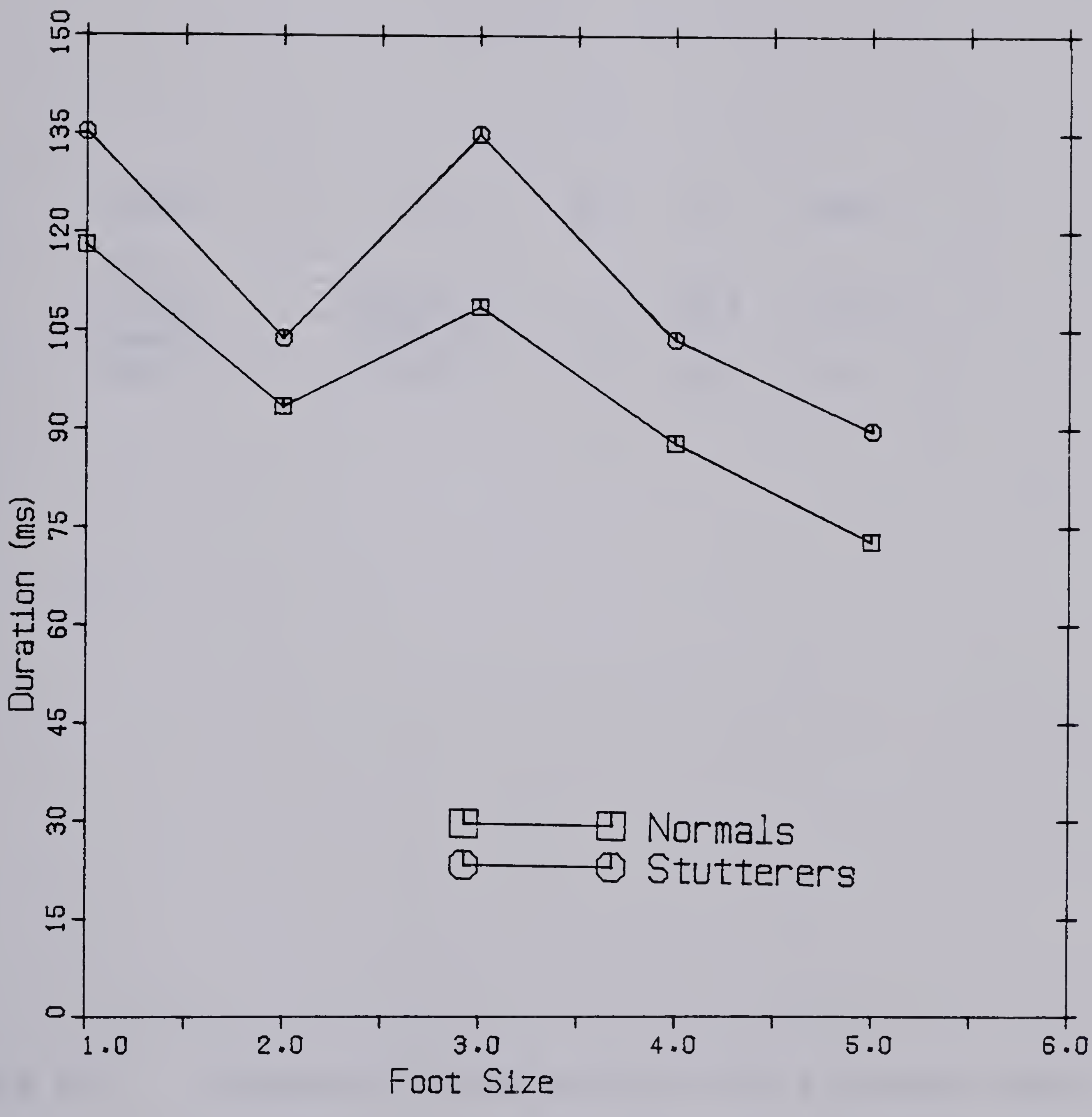


Figure 4.5 Stressed vowel duration as a function of foot size.

SOURCE	SS	df	F	PROB
FOOT				
Linear	63093.9	1	26.5	0.001
Quadratic	2495.43	1	0.7	
Cubic	11281.2	1	9.6	0.01

Table 4.6 Summary of trend analysis for stressed vowels.

F=FOOT SIZE N=NORM S=STUTT

	F5N	F4N	F5S	F2N	F4N	F2S	F3N	F1N	F3S	F1S
MEANS	72.8	87.8	89.7	93.4	103.6	103.8	109.	118.	134.9	135.9
F5N		1.8	2.0	2.4	3.6	3.6	4.2	5.3**	7.3**	7.3**
F4N			0.2	0.6	1.9	1.9	2.4	3.5	5.5**	5.6**
F56				0.4	1.6	1.7	2.2	3.3	5.3*	5.4*
F2N					1.2	1.2	1.8	2.9	4.9*	4.9*
F4N						.03	0.6	1.7	3.7	3.7
F2S							0.6	1.7	3.6	3.7
F3N								1.1	3.1	3.1
F1N									2.0	2.0
F3S										.05
F1S										

* P<0.05 ** P<0.01

Table 4.7 Results of Tukey A test for stressed vowels.

monosyllable to five syllable unit, stutterers showed a compression of about 33.7%. Thus, with the lesser degree of compression, stutterers seem to maintain slower rates and longer stressed vowel durations, compared to normals.

Temporal compression of stressed vowels was also present for RUSS (Fig. 4.6). The extent of compression of the stressed vowels in "credit" decreased by about 17.4% from disyllable unit to six syllable unit. This lesser degree of compresion in RUSS is attributable to the fact that compression was observed for the vowel in "credit", embedded in rhythmic units of varying sizes. Whereas, for the principal experiment, the duration of stressed vowels were obtained from vowels of different phonetic categories.

C. First Unstressed Vowel Duration (1USV)

The analysis of variance on the duration of 1USV for foot sizes, F2 to F5 was carried out. There were four tokens for F2 and F4; three tokens for F3, and one token for F5. The results of ANOVA summarized in Table 4.8 showed that the difference in means for foot sizes was statistically significant ($F=11.46$, $df=3$, $p<0.001$). A statistically significant F value was also obtained for group means ($F=16.35$, $df=1$, $p<0.0001$), and for subject nested within group factor ($F=3.22$, $df=16$, $p<0.0001$).

Fig. 4.7 illustrates the first unstressed vowel as a function of foot size for stutterers and normals. The plots for the two groups showed temporal compression as a function of foot size.

Further, the Tukey A test was performed to identify the pairs of means that contributed to the significant F value for foot sizes. These results are presented in Table 4.9. Two pairs of means had differences that were statistically significant.

Fig. 4.7 also shows that the plots for the two groups run parallel to each other indicating no group by foot size interaction. This lack of interaction was further confirmed statistically.

The significant differences between the two groups comes from the difference in the average duration obtained for the two groups.

Qualitatively, stutterers and normals differ in the extent of compression of the 1USV. Although stutterers have longer vowel durations, the extent of compression is only 9.8% from disyllable to five syllable unit. Whereas, for normals, compression of

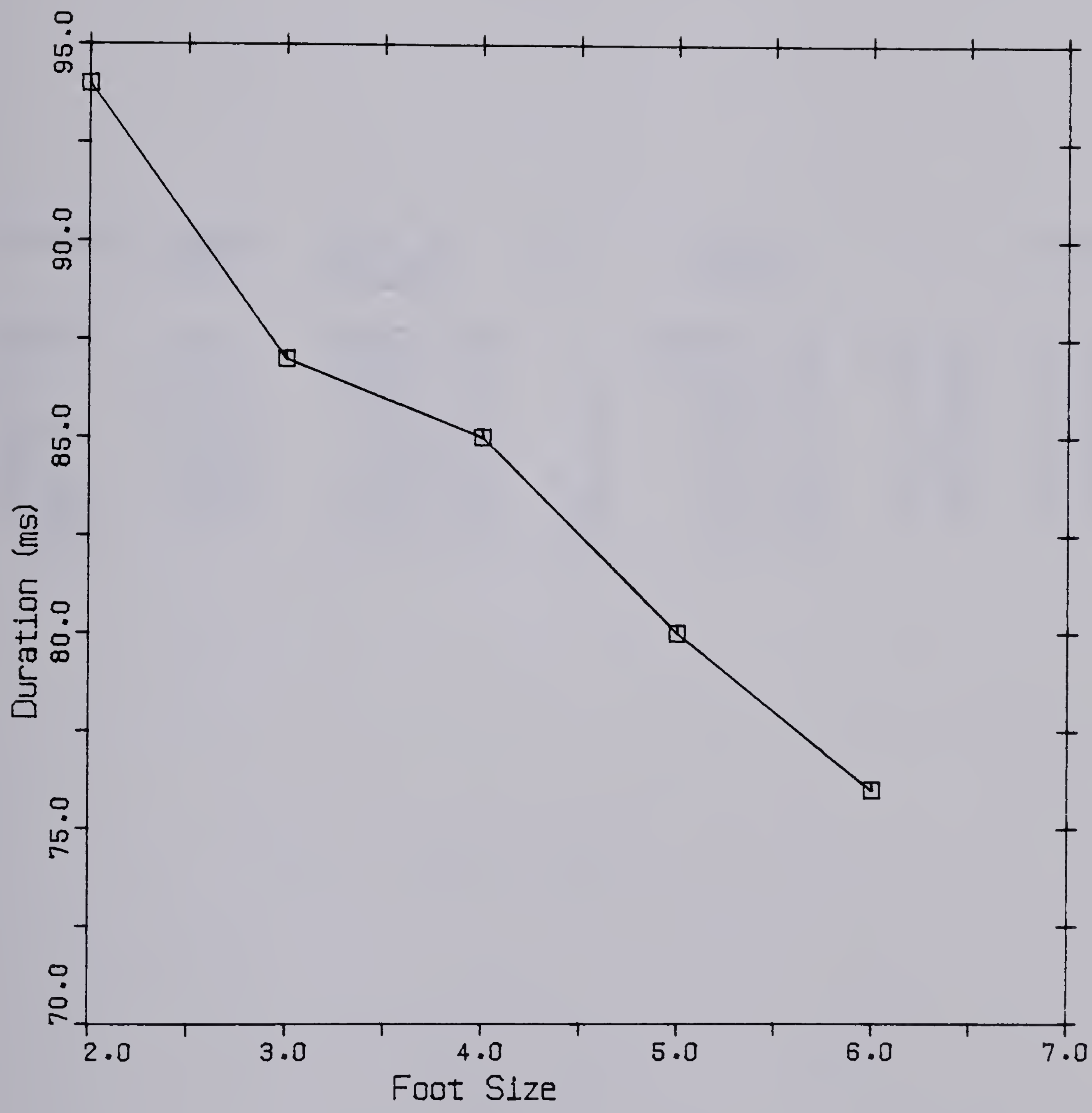


Figure 4.6 Stressed vowel duration as a function of foot size for RUSS.

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(G)	986076.06	1	986076.06	591.42	0.0000
G	S(G)	27261.13	1	27261.13	16.35	0.0009
F	SF(G)	17351.72	3	5783.91	11.46	0.0000
S(G)	T(GSF)	26676.94	16	1667.31	3.22	0.0001
GF	SF(G)	336.93	3	112.31	0.22	0.8802
SF(G)	T(GSF)	24219.72	48	504.58	0.97	0.5275
T(GSF)		111919.50	216	518.15		

Table 4.8 ANOVA summary for first unstressed vowel.

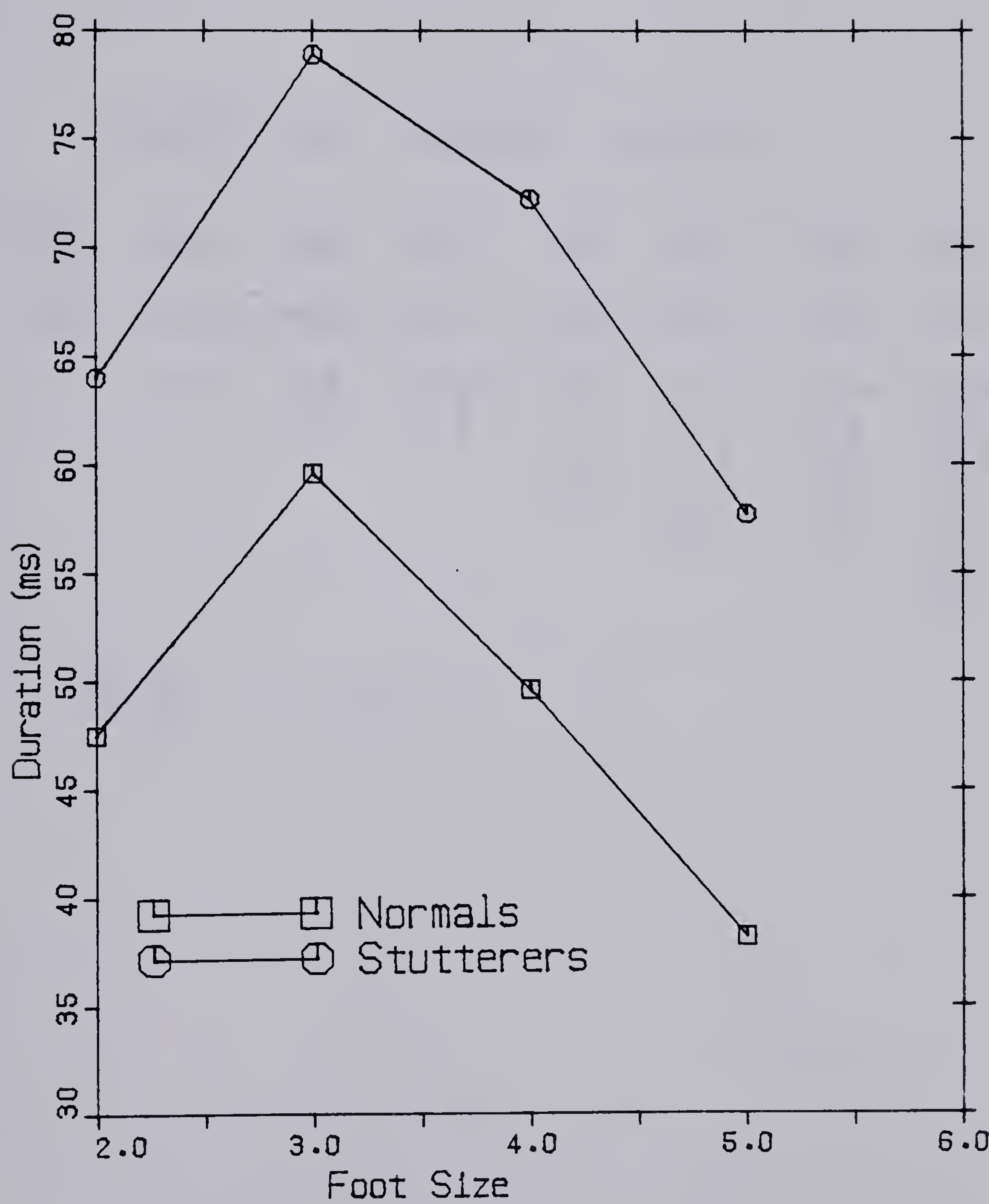


Figure 4.7 First unstressed vowel duration as a function of foot size.

F=FOOT SIZE N=NORM S=STUTT

	F5N	F2N	F4N	F5S	F3N	F2S	F4S	F3S
MEANS	38.2	47.5	49.6	57.7	59.6	64.0	72.2	78.9
F5N		1.2	1.5	2.6	2.9	3.4	4.5*	5.4**
F2N			0.3	1.4	1.6	2.2	3.3	4.2
F4N				1.1	1.3	1.9	3.0	3.9
F5S					0.3	0.8	1.9	2.8
F3N						0.6	1.7	2.6
F2S							1.1	2.0
F4S								0.9
F3S								

* P<0.05 ** P<0.01

Table 4.9 Results of Tukey A test for first unstressed vowel.

approximately 19.6% occurs.

The two groups also differ in their variability within their groups. The means for normals ranged from 40 ms to 59 ms, whereas, for stutterers the range was considerably larger, from 40 ms to 83 ms This within group variability is illustrated in Fig. 4.8a and 4.8b in the form of frequency distribution of means for stutterers and normals respectively. The frequency distribution for stutterers show a greater spread than for normals.

Data for RUSS also showed temporal compression of 1USV as a function of foot size (Fig. 4.9) up to five syllable unit. For the longest unit, there was a sharp increase in duration. The extent of compression for RUSS was, however, only 11.1% from disyllable to six syllable foot. The lesser degree of compression noted for the stressed vowels in "credit" compared to stressed vowels in the principal experiment is most likely due to the fact that in the RUSS, the compression of the same vowel was observed for the different foot sizes, whereas in the principal experiment vowels belonging to different phonetic categories were present.

D. Total Unstressed Vowel Duration (TUSV)

The analysis of variance was carried out on total unstressed vowel durations for foot sizes F2 to F5. There were four tokens for F2 and F4; three tokens for F3 and one token for F5. The results of the ANOVA (Summarized in Table 4.10) showed that the difference between means for foot sizes was significant ($F=243.71$, $df=3$, $p<0.001$). Significant differences for group means were also found ($F=18.63$, $df=1$, $p<0.0005$); stutterers having longer durations relative to normals. Again, a significant F value was obtained for the subject nested within group factor ($F=10.76$, $df=16$, $p<0.001$)which was consistent with the greater within group variability seen for stutterers for the mean durations of stressed vowel, 1USV, the TUSV and the ISI.

Similar to the trend noted for the overall ISI, a significant group type by foot size interaction was present ($F=6.75$, $df=3$, $p<0.0007$). Illustrated in Fig. 4.10 is the greater than linear increase in the total duration of unstressed vowels as a function of foot size for both groups. Note that the curves for both stutterers and normals lie above the linear extrapolation which is indicated by split lines.

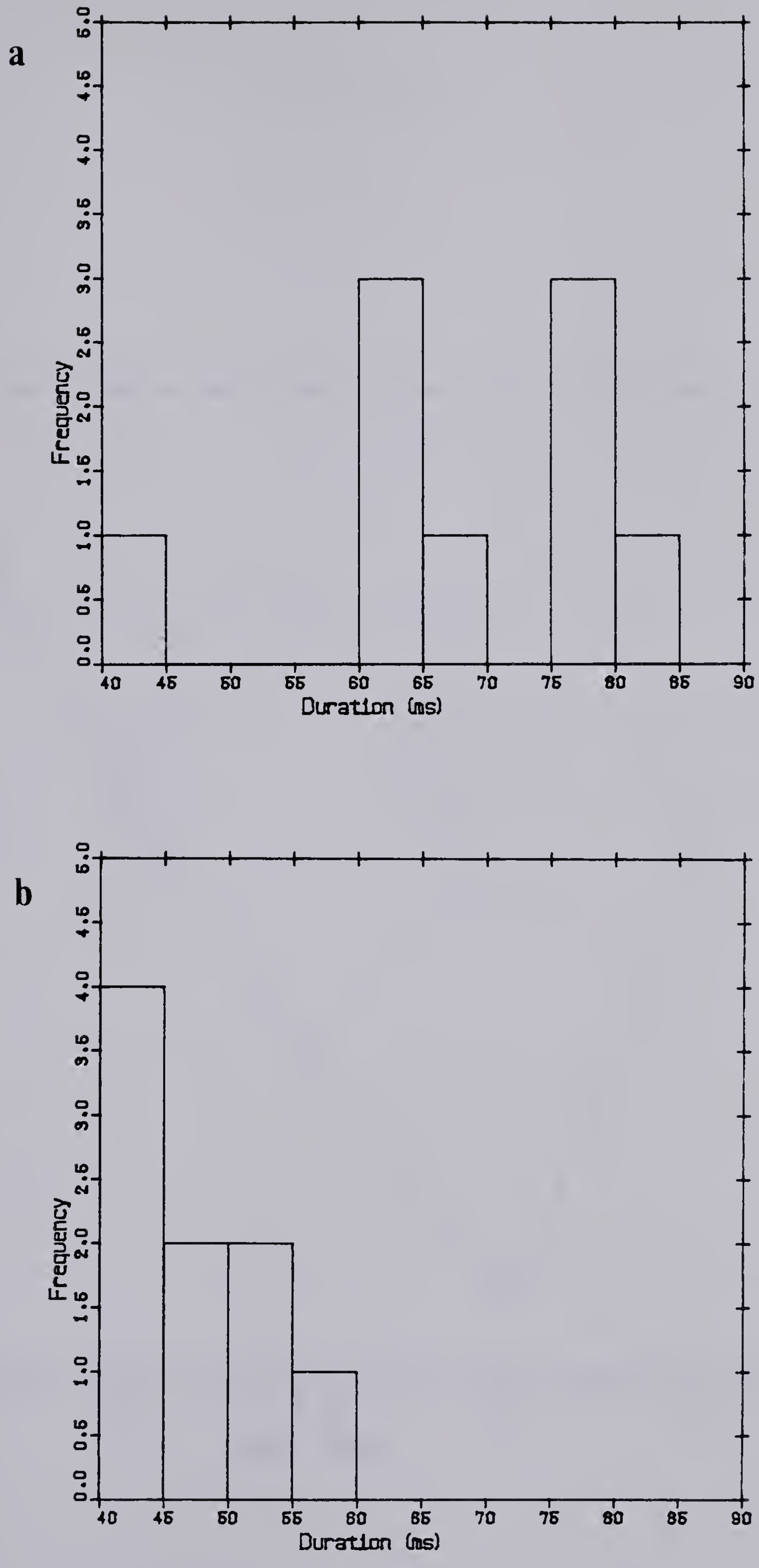


Figure 4.8 Frequency distribution of means for first unstressed vowel duration: (a) Stutterers (b) Normals.

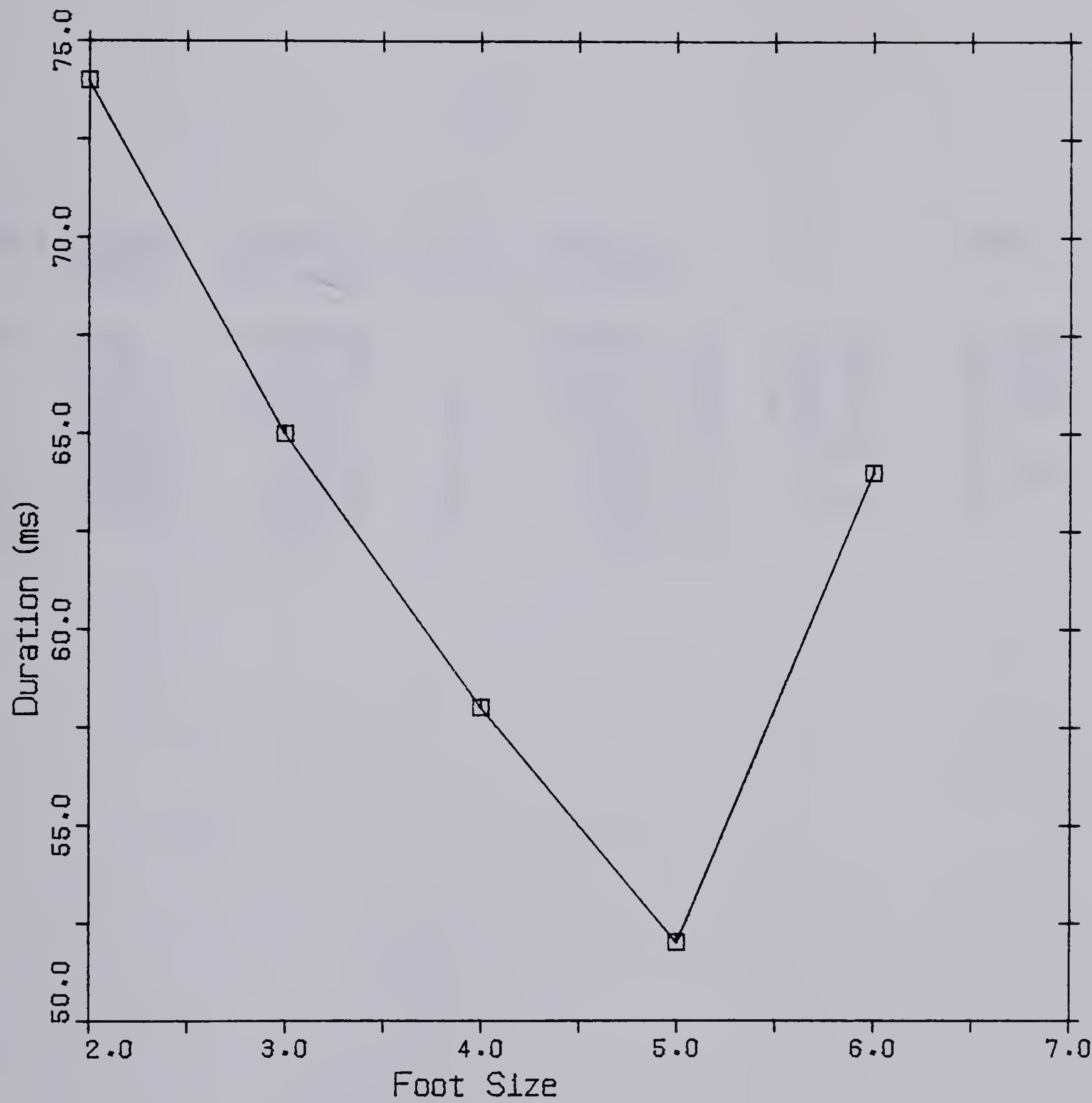


Figure 4.9 First unstressed vowel duration as a function of foot size for RUSS.

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(G)	8759903.	1	8759902.72	921.83	0.0000
G	S(G)	177013.	1	177012.50	18.63	0.0005
F	SF(G)	2499411.	3	833137.09	243.71	0.0000
S(G)	T(GSF)	152043.	16	9502.68	10.76	0.0
GF	SF(G)	69174.	3	23058.13	6.75	0.0007
SF(G)	T(GSF)	164089.	48	3418.51	3.87	0.0
T(GSF)		190777.	216	883.23		

Table 4.10 ANOVA summary for total unstressed vowels.

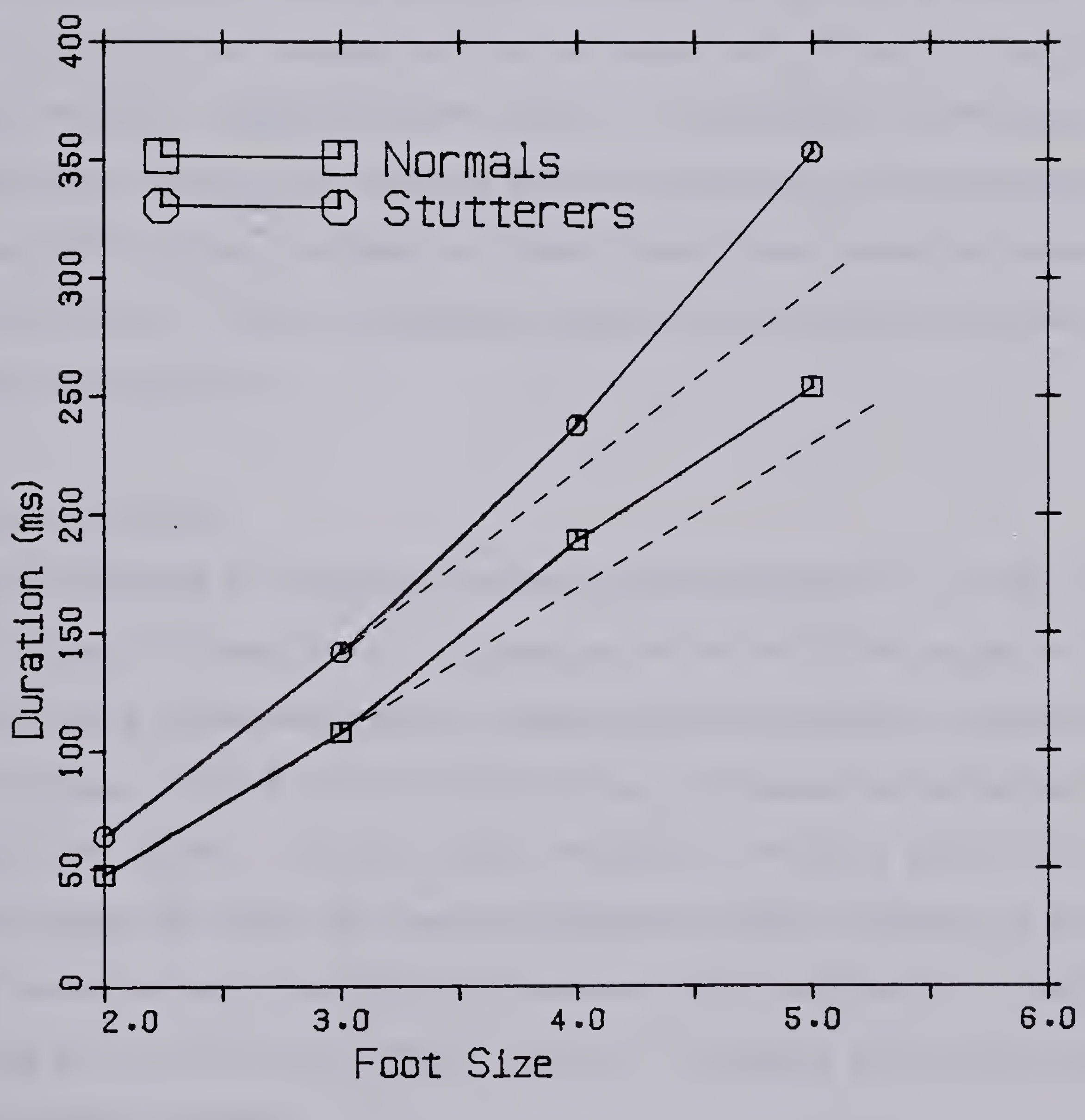


Figure 4.10 Total unstressed vowel duration as a function of foot size.

Tukey A test was done to identify pairs of means that contributed to the significant F value for foot sizes and for foot by group interaction. These results are tabulated in Table 4.11.

For stutterers, significant differences were obtained for the successive pairs of means, F2 and F3, ($Q=4.00$, $p<0.05$); F3 and F4, ($Q=4.97$, $p<0.05$); F4 and F5, ($Q=5.94$, $p<0.01$). For normals, significant difference was present only between F3 and F4 ($Q=4.16$) at the 0.05 level.

For the RUSS, a linear increase in the TUSV duration was seen as a function of foot size (Fig. 4.11) up to the four syllable unit. For the longer units, F5 and F6, the increase actually is less than linear, suggesting some temporal compression for the longer units. This lesser than linear increase for the longer units corresponds to the unexpected sharp increase in the 1USV for the six syllable unit. These observations should be viewed in the light of the fact that for RUSS, the speakers showed an almost constant rate across rhythmic units of varying sizes.

E. Intervowel Interval (IVI)

Analysis of variance for intervowel intervals was carried out for F1 to F5 with four tokens for F1, F2 and F4; three tokens for F3 and one token for F5. The results of ANOVA (Summarized in Table 4.12) showed that both stutterers and normals had increase in IVI as a function of foot size ($F=30.54$, $df=4$, $p<0.001$). This is, however, expected due to the mere increase in the length of the units. Most importantly, the plots (Fig.4.12) for both stutterers and normals fall below the linear extrapolation, which is indicated by split lines, thus showing some degree of temporal compression. This compression is particularly evident in the graph from F2. For normals the rate of increase is slower than linear for units of three syllables or more.

Interestingly, for RUSS, (Fig.4.13) for five normal speakers, the IVI showed no temporal compression, but in fact the curve lies above the linear extrapolation, which is indicated by split lines. At F6 in particular, the curve deviated considerably from the linear extrapolation, indicating that temporal expansion had occurred.

Significant differences were also obtained for group means ($F=11.10$, $df=1$, $p<0.0042$), stutterers showing significantly longer duration than normals. Similar to the

F=FOOT SIZE N=NORM S=STUTT

	F2N	F2S	F3N	F3S	F4N	F4S	F5N	F5S
MEANS	47.5	64.0	108.	141.8	189.1	237.5	253.7	353.3
F2N		0.8	3.1	4.8**	7.3*	9.8**	10.6**	15.7**
F2S			2.3	4.0*	6.4*	8.9**	9.7**	14.8**
F3N				1.7	4.2*	6.6**	7.5**	12.6**
F3S					2.4	4.9*	5.7**	10.8**
F4N						2.5	3.3	8.4**
F4S							0.8	5.9**
F5N								5.1*
F5S								

* P<0.05 ** P<0.01

Table 4.11 Results of Tukey A test for total unstressed vowels.

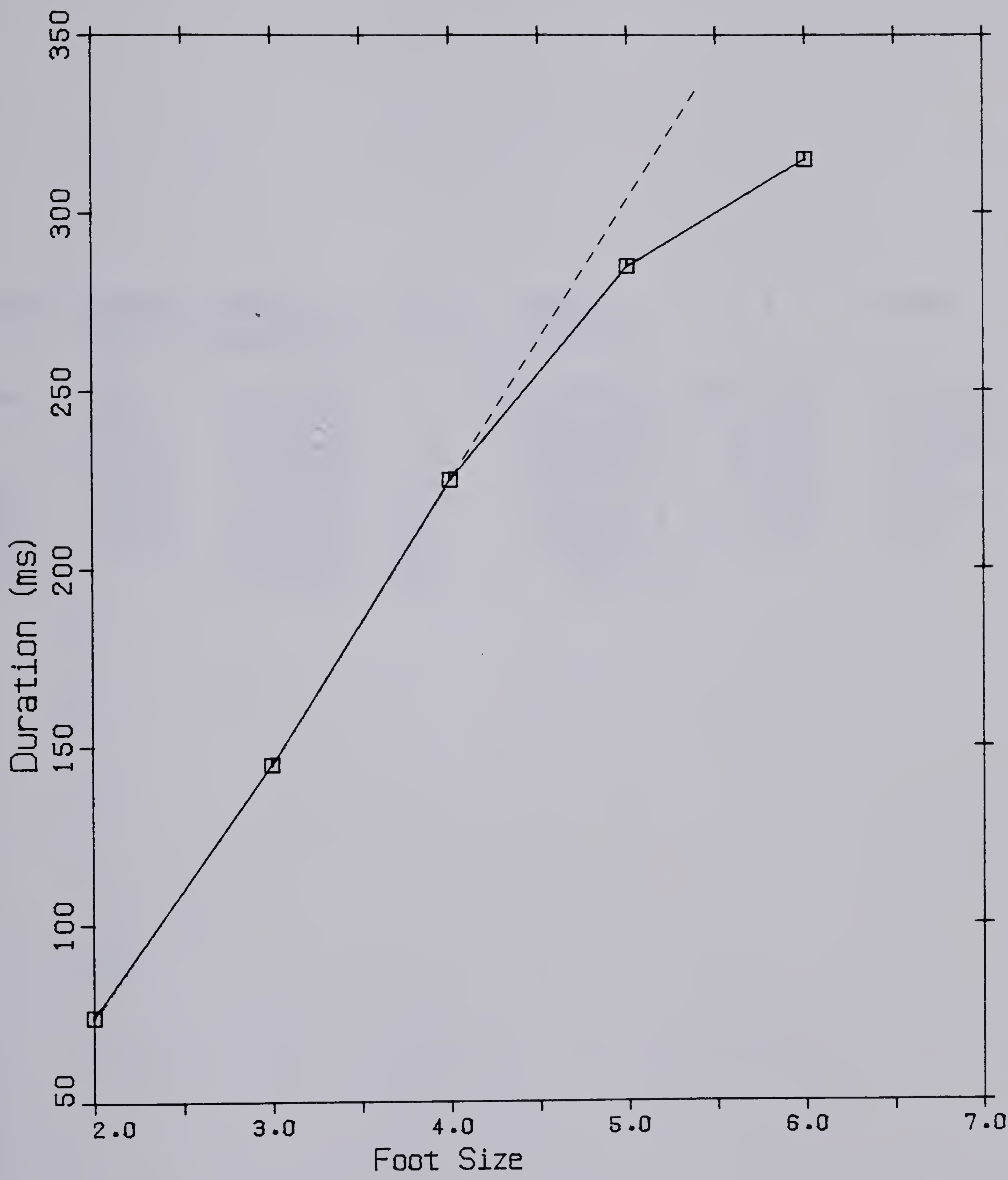


Figure 4.11 Total unstressed vowel duration as a function of foot size for RUSS.

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(G)	34171987.	1	34171987.2	287.08	0.0000
G	S(G)	1321080.	1	1321080.2	11.10	0.0042
F	SF(G)	7702636.	4	1925659.0	30.54	0.0000
S(G)	T(GSF)	1904545.	16	119034.1	21.08	0.0
GF	SF(G)	972680.	4	243170.0	3.86	0.0072
SF(G)	T(GSF)	4035437.	64	63053.7	11.17	0.0
T(GSF)		1524524.	270	5646.4		

Table 4.12 ANOVA summary for intervowel intervals.

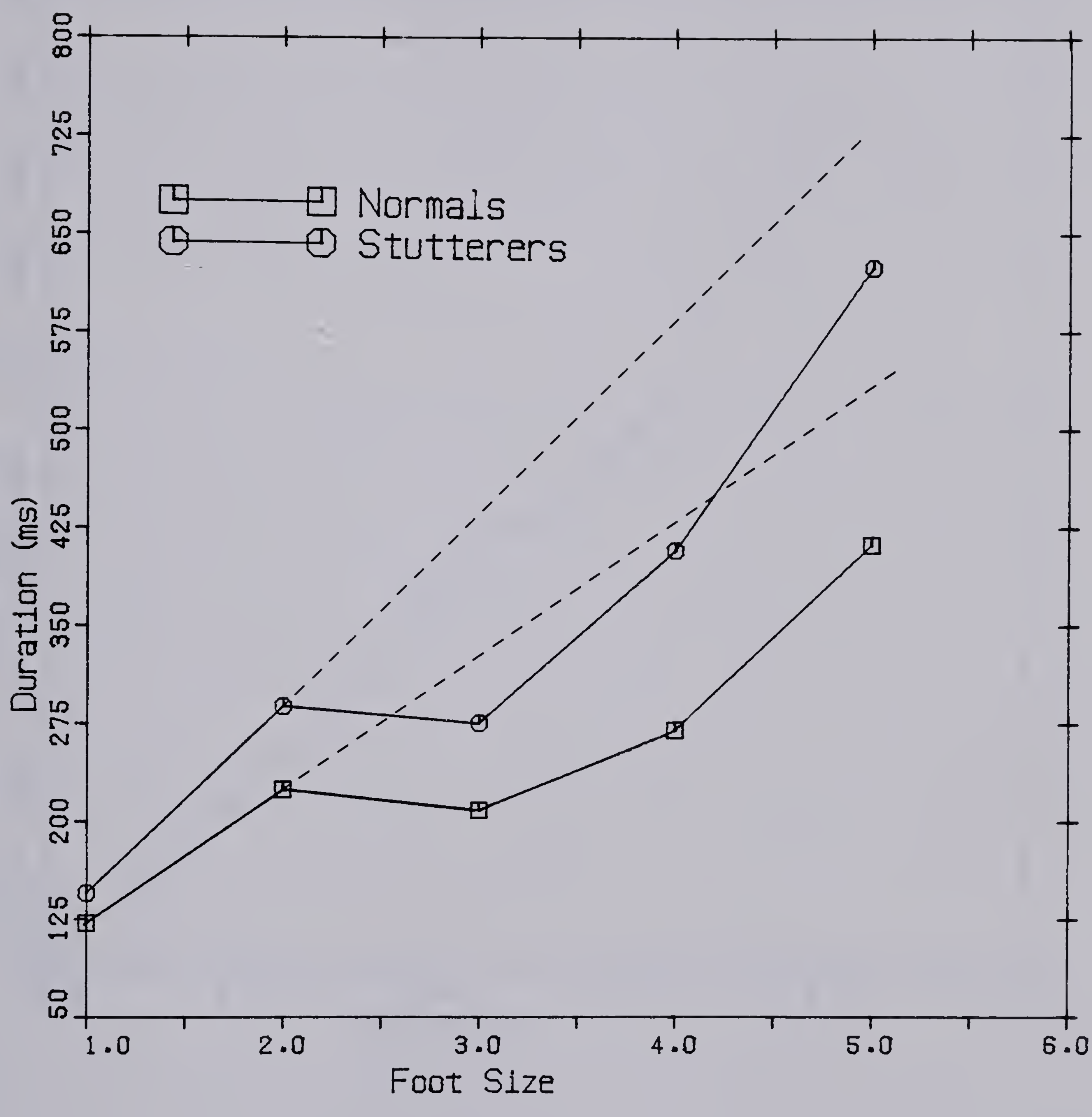


Figure 4.12 Intervowel interval as a function of foot size.

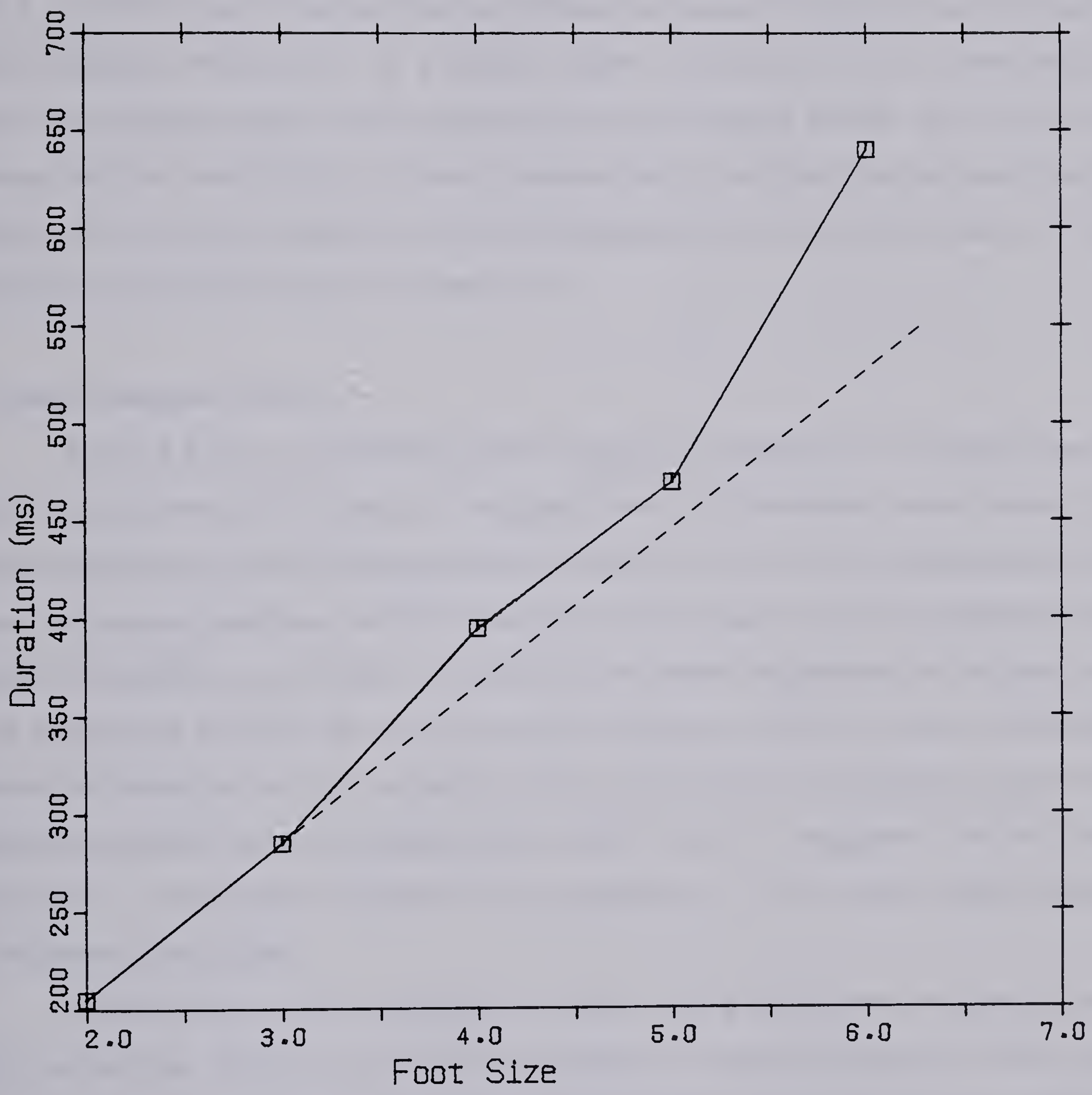


Figure 4.13 IVI as a function of foot size for RUSS.

trend noted for the interstress interval, the difference between stutterers and normals become progressively larger as a function of foot size, being the greatest for F5. Also note that, for stutterers, the increase from F4 to F5 is at a rate greater than linear. This was confirmed by statistically significant group type by foot size interaction ($F=3.86$, $df=4$, $p<0.007$). Fig.4.14 shows that the difference between stutterers and normals for the interstress intervals are to a greater extent contributed by their differences in intervowel intervals than by their differences in vowel durations. Further, Fig.4.15a, b and c shows that the contribution of different components to the differences between the two groups for the overall interstress interval corresponds to the proportion each of these components hold within a given rhythmic unit.

F. Ratios: Relative Timing

Fig.4.16 a, and b illustrate the ratios between components of in rhythmic units of various sizes. Note that the ratios of stressed vowel to unstressed vowel duration, and intervowel interval to total unstressed vowel duration are similar for a given sized unit for both normals and stutterers, with the exception of the longer units. This indicates that this group of stutterers were similar to normals in the internal organization of rhythmic units. The differences between the two groups are, however, in terms of rate. As mentioned earlier, stutterers differ from normals in terms of the extent of compression, and in their absolute durations for all the components within a unit. It is suggested that this lesser degree of compression facilitates the maintenance of the relative timing between components within a unit.

Confirmation of this observation on relative timing comes from the data on RUSS for five normals. Table 4.13 shows that the ratios of Intervowel interval to total vowel duration is almost constant for these speakers across foot sizes, with the exception of the six syllable unit (F6). This temporal invariance corresponds with the almost constant rate that was observed across foot sizes, including the longest unit.

This observation on relative timing is significant because, both stutterers and normals have demonstrated with consistency that certain relative timing rules operate within rhythmic units, possibly to maintain the rhythm specific to the language.

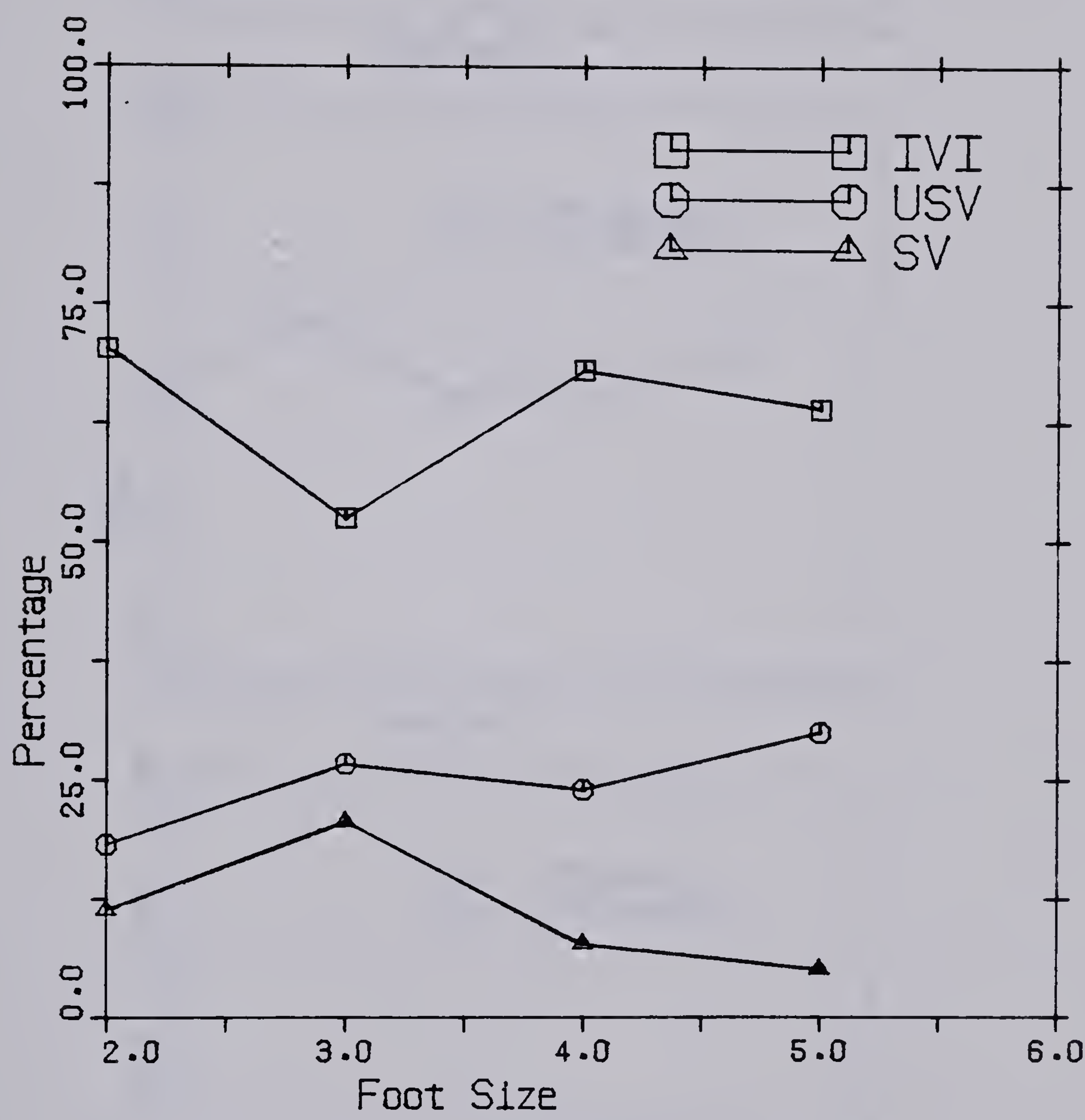


Figure 4.14 Percentage contributions of IVI, SV, and USV to differences in ISI.

a

b

c

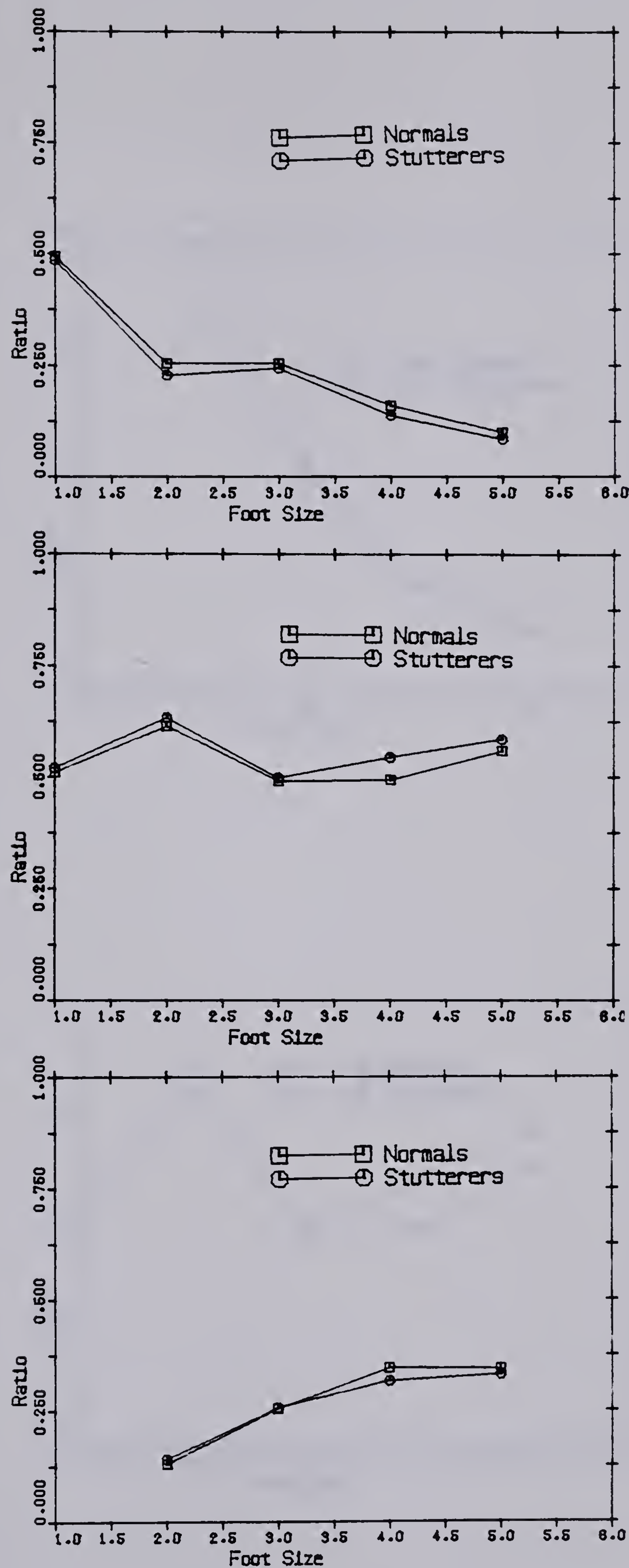
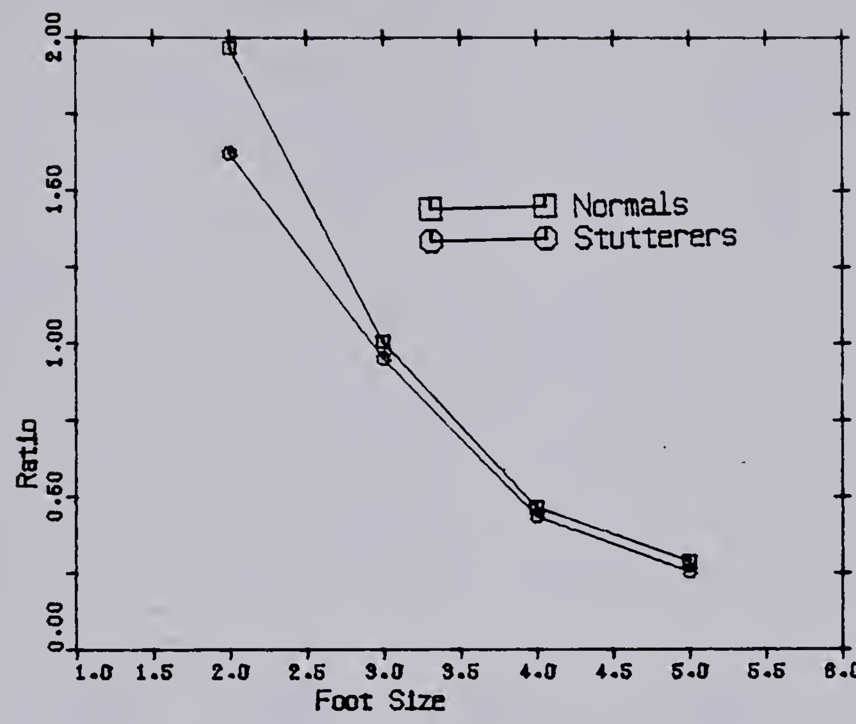


Figure 4.15 Ratios of components within rhythmic units: (a) SV/ISI (b) IVI/ISI (c) USV/ISI.

a



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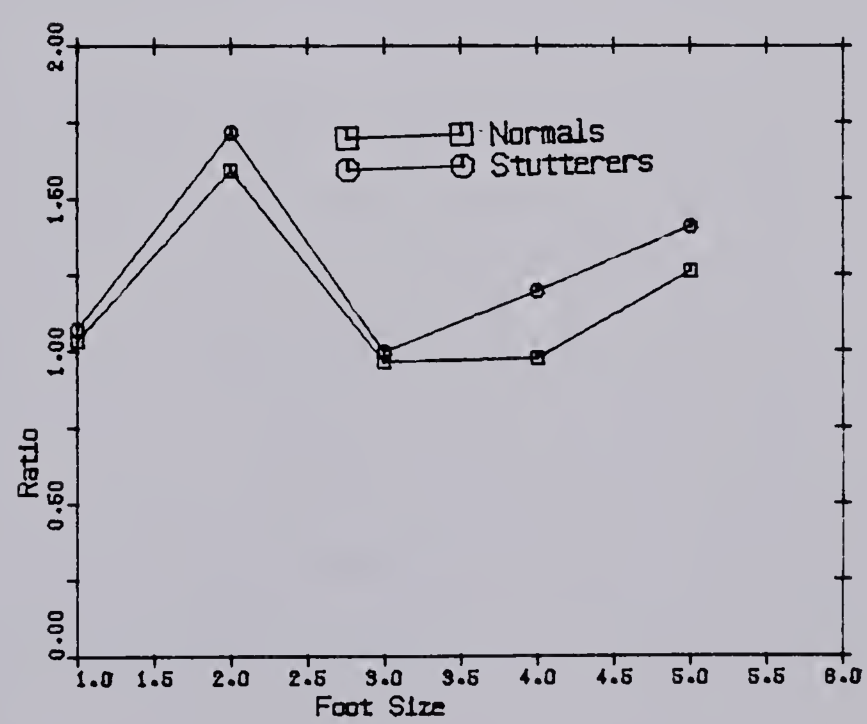

Figure 4.16 Ratios of components within rhythmic units: (a) SV/USV (b) IVI/TVD.

	F2	F3	F4	F5	F6
IVI/TVD	1.23	1.23	1.27	1.28	1.63

Table 4.13 Ratios of intervowel interval to total vowel duration for RUSS.

G. Summary

In summary, the results showed that the interstress intervals increase as a function of foot size for stutterers and normals. However, stutterers consistently showed longer interstress intervals, indicating consistently slower than normal rates. The difference between the two groups for ISI increased progressively as a function of foot size. Although this difference for ISI between the two groups is attributed to their differences in SV, USV and IVI, a significant percentage of this difference was accounted for in their differences for IVI. The differences between stutterers and normals for vowel durations accounted for a relatively smaller percentage of the overall difference in ISI. The contributions of the different components to the difference between the two groups for the overall ISI, corresponded to the proportion in which each of these components were present within the rhythmic units.

The increase in ISI as a function of foot size was as expected, due to the increasing number of syllables. This increase was less than linear, suggesting some degree of temporal compression of the components of the units. Temporal compression was indeed observed for SV vowel, 1USV, and IVI as a function of foot size. The temporal compression of these components resulted in rate increase, but reached a plateau from F3 to F4. Following this stabilization, the rate decreased for the longest unit. This rate decrease is associated with the greater than linear increase that occurs for the total unstressed vowels. For stutterers, the rate decrease for the longest unit is contributed by both, increase in TUSV durations and IVI. While temporal compression of selected components facilitates rate increase, temporal expansion of TUSV seems to counteract the effects of compression to some extent. Thus, the selective temporal compression and expansion of components within rhythmic units seem to be an effective rate control strategy. Moreover, this rate control mechanism also seem to interact with certain relative timing rules that operate to maintain a critical relative timing between components of a rhythmic unit.

While stutterers showed trends similar to normals up to F4, for SV, 1USV, IVI, and TUSV; they differed from normals in the extent of compression and in their absolute durations of vowels and intervowel intervals. Most importantly, despite their differences, stutterers were similar to normals in their ratios between between components for a given

sized unit. The differences between the two groups were the greatest for the longest unit.

For F5, both stutterers and normals showed a decrease in rate. Normals seem to achieve this rate decrease through increase in TUSV while maintaining the timing regularities, i.e., temporal compression of SV, 1USV, and IVI. Stutterers, on the other hand, achieve this rate decrease through increase in the durations of TUSV and IVI. The increase in IVI consequently results in a greater ratio of intervowel interval to total vowel duration for the longest unit for stutterers.

For RUSS, normal speakers showed a linear increase in ISI, thus resulting in an almost constant rate. However, similar to the results of the principal experiment, temporal compression of SV and 1USV were observed as a function of foot size. Unlike the results of the principal experiment, temporal compression of IVI was not observed. In fact for IVI, the curve lies above the linear extrapolation. For the longest unit (F6), the speakers deviated from the temporal regularities seen for the other units for RUSS. In contrast to the linear increase noted for the other units, the TUSV showed temporal compression for F6. Counteracting these effects are the sharp increase for 1USV and IVI. It appears that temporal compensations between components are necessary to regulate rate and rhythm.

V. DISCUSSION

In this chapter the issue of isochrony will be first discussed. Following this, the most significant findings: the temporal compression of intervowel interval, stressed vowel and first unstressed vowel, rate, and relative timing will be discussed. These discussions will be supplemented with implications for future research, both in the field of stuttering and in normal speech perception and production. Finally, a potential model of speech timing will be proposed on the basis of the present findings.

A. Isochrony

The results of the present study showed no evidence to support the isochrony hypothesis. According to this hypothesis interstress intervals should be constant regardless of the number of intervening unstressed syllables. From Fig. 4.1, it is evident that the interstress intervals increase with increase in the number of intervening unstressed syllables. This finding is consistent with all the earlier studies that have attempted to find isochrony in production data (e.g., Nakatani, 1981; Lehiste, 1973, 1977; Lea, 1974, etc.) despite the fact that the samples analysed in earlier studies differed from the present study. Nakatani, for example, used reiterant speech and Lehiste obtained measurements on target words embedded in carrier phrases. Somewhat similar to the present study, Lea (1974) analysed sentences in paragraphs and rejected the notion of isochrony on the basis of his results which showed linear increase in interstress intervals as a function of number of syllables in the interval. A linear trend is what would be expected if speakers used a syllable timed rhythm. However, for ideal syllable isochrony to occur the percentage increase should be greater than what is observed in this study. If syllable isochrony were present, the plots for both normals and stutterers would be closer to the linear extrapolation indicated by split lines in Fig. 4.1. In the same figure note that the observed values of interstress intervals do not match the ideal values for stress isochrony which is indicated by the dotted horizontal lines. With respect to the interstress intervals, interestingly, stutterers were similar to normal speakers in that they neither showed evidence of stress isochrony nor syllable isochrony. But the two groups differed significantly on measurements of interstress intervals, and the components that comprise

the interval: the unstresed vowel durartions, stressed vowel durations and the intervowel intervals. Stutterers had consistently longer durations on all measures. Furthermore, the differences between stutterers and normals progressively increased as a function of foot size. This point is well illustrated in Fig. 4.1 where the widening of the gap between plots for stutterers and normals can be observed as a function of foot size. In other words, the stutterers' fluent speech is likely to be perceptibly distinct from normals' speech for monosyllables because a difference of about 16% between stutterers and normals is quite close to the just noticeable difference (JND) which is about 20% (Klatt, 1976). If, however, listeners are required to make judgements of normality of stutterers' fluent utterances, the monosyllables are likely to receive ratings towards the "normal" end of the scale. The ratings for the longer rhythmic units will be farther away from "normality". This growing difference between the two groups for longer rhythmic units not apparent for the monosyllabic unit demonstrated the importance of using continuous speech in the study of rhythm as opposed to words embedded in carrier phrases or reiterant speech.

Specific mention should be made of the interstress interval for the five syllable foot. Particularly, stutterers showed a mean increase of about 310 ms from F4 to F5 which is approximately 42% increase. This difference in duration between F4 and F5 units in itself is well above the overall mean duration for the monosyllabic foot which is approximately 278 ms. Normals, likewise, showed an increase of 35% from F4 to F5. However, the difference in duration which is about 190 ms is not above the mean duration of a F1 for normals. Interestingly, for rhythmic units in special sentences (RUSS) used in the auxiliary experiment, normal speakers showed an average increase of about 115 ms from F4 to F5, and a dramatic increase of about 221ms occurs between F5 and F6. These data suggest that due to unfamiliarity of longer rhythmic units, speakers are likely to break a larger unit either by introducing a pause or by stressing an unstressed vowel. Either way, speakers seem to have a tendency to maintain a critical duration between two main stresses. This may be purely due to psycho-physical limitations. The pause, for instance, may well correspond with the moment of inhalation. Other researchers have addressed this issue for its significance in motor planning. Nooteboom (1975), quoting Miller (1956), commented that in general the length of production programmes do not exceed the magical number of seven syllables. Nooteboom and Cohen (1975) analysing the phonemic

errors that occur as "slips of tongue" noted that anticipations and transpositions occur when two adjacent syllables interact which may be reflective of the amount of speech material simultaneously present in the speech program. In this context, they concluded that the speaker does not seem to look much farther ahead of seven syllables. From this observation they predicted that the temporal integration of stretches of speech will not consist of more than seven syllables. Fromkin (1973) noted that "spoonerisms" or slips of tongue exhibit the correct stress pattern, which suggests that stress plays an important role in the organization of speech perception and production.

At the processing end, Kozhevnikov and Chistovich (1965) investigated the recognition of sentences from which much of the phonemic information was removed by passing the signal through a band pass filter that passed only the frequency range from 906 to 1141 Hz. Listeners' performance on the recognition task improved with increasing length of the sentence but only up through seven syllables. The recognition declined rapidly for sentences with eight, nine, ten, eleven, and twelve syllables. They concluded that the approximate limit of seven syllables is determined by the limited capacity of the processing memory. Similar findings were reported by Potapova (1975) that vowel length estimation by listeners were more reliable for sentences five to eight syllables long. In sentences that consisted of ten and eleven syllables, the estimation correlated poorly with objective measurements of syllable durations. They concluded that the "greater number of syllables constituting the rhythmic succession leads to poorer results in the perception of syllable (vowel) duration".

There is reason to believe that the limits in processing has influenced humans in structuring their languages. Very recently, Dauer (1983) observed that in continuous natural texts interstress intervals contain a maximum of five syllables for English and that they may contain very rarely up to nine or ten in Spanish, Greek, or Italian. However, the majority of interstress intervals seem to contain two to six syllables for the languages that were examined.

A frequency count made on the two texts used in this study (Table 4.4) showed that disyllabic rhythmic units (with a single unstressed vowel) have the highest frequency (45%) for both the narrative and the dialogue. For the dialogue, for instance, the six syllable units were not present, and for the narrative the six syllable units had a frequency of only

2.8%.

Particular mention has to be made of the fact that measurements were not made on six syllable unit because most stutterers and some normal speakers did not successfully produce these segments free of pause or articulation errors. Since measurements for each subject were required for all the foot sizes, the six syllable unit was excluded.

Based on the frequency count, isochrony in perception can now be explained. English stresses are likely to be perceived as occuring at isochronous intervals, at least most of the time, because of the high frequency of interstress intervals with alternating stressed and unstressed vowels. The high frequency of this alternating stress pattern would be preferred for information processing. The suggestion here is that stresses which are cues to word identity (Gaitenby and Marmelstein, 1977) occur on most important words (Lea, 1976) carrying high information value. These words will have to occur within a critical interval for efficient processing of information. Further support to this notion is the fact that stresses occur at an average interval of 0.4 seconds. Despite the absolute durational increase of interstress intervals with increasing foot size, the interstress intervals measured up to five syllables fell within a narrow range of 0.2 seconds to 0.7 seconds for normals (239 ms to 738 ms). Even the interstress intervals for stutterers which were significantly greater than normals' fell within the range of 0.2 seconds to 1.06 seconds (278 ms to 1067 ms). The increase in the range for stutterers is primarily due to the longest unit, the five syllable unit. It is reasonable to assume that both stutterers and perhaps some normal speakers interrupted the five syllable unit with a pause. Therefore, if the range of interval between monosyllable unit and four syllable unit is considered for both groups, the present results are remarkably consistent with earlier studies. In the present data then, stutterers show a range of 0.2 seconds to 0.7 seconds; normal speakers show a range of 0.2 seconds to 0.5 seconds. The upper end of the range for normal speakers in this study is very close to the average interval of 0.4 seconds reported by Lea (1974). This range is also consistent with other findings. Abe (1967, in Allen, 1975) reported a range of 0.4 to 0.7 seconds, Allen (1972) observed a range of 0.3 to 0.6 seconds. More recently, Dauer (1983) analysed several languages and found that the duration of majority (75%) of the interstress interval fell within a range of 0.3 to 0.7 seconds.

The interval range from samples (RUSS) analysed for four normal speakers in the auxiliary experiment is also consistent with the principal data. In fact, for these sentences the intervals ranged from 0.3 to 0.8 seconds from disyllable to five syllable unit.

These data not only concur with the widely observed data (Dauer, 1983), they also parallel the findings on motor rhythms. Allen (1975) reviewing the relationship of speech rhythm to other motor rhythms, noted that the preferred natural rates for motor acts on the average, range between 0.2 to 1.0 seconds between acts. In addition, Lea, (1974) found that the syntactically dictated pauses were one or two units interruption of rhythm.

Thus, the results from the present study on the frequency of occurrence of rhythmic units, the mean interstress interval and the range of interval reinforce several findings on speech rhythm and motor rhythms

It is therefore reasonable to postulate a hypothesis that it is the temporal constraint in processing that determines the magnitude of a rhythmic unit that is planned. It may be argued that the interstress intervals are governed by the lexical and phonological make up of the language. Since these linguistic structures have to be integrated to be communicatively effective in terms of processing and production, the limitations faced by the language user for processing information temporally is likely to modify the structure of the language over time. There is even evidence to the effect that the rhythm of a language is likely to change from a stress-timed to a syllable timed rhythm as a consequence of articulatory shortening that may occur. For instance, Brazilian Portugese is reported to be undergoing a transition from syllable to stress timed rhythm (Major, 1981). Modern Thai (Luangthongkum, 1977, see Dauer, 1983) has been reported as being stress timed because of the introduction of polysyllabic and grammatical words into the monosyllabic structure of ancient Thai.

Due to similar reasons children's earliest utterances which usually consist of monosyllabic content words are described as being syllable timed (Allen and Hawkins, 1978). However, with the acquisition of function words and polysyllabic words, the child begins to acquire the adult rhythm. Here again, the point to be reiterated is that, because of children's relatively lowered capacities to attend and process information temporally, the temporal constraints for the occurrence of information loaded components of speech will be even more stringent. By the virtue of maturity, the child will acquire the ability to

process and program longer units of speech and this ability is likely to increase, of course, up to a certain limit. This temporal limit appears to be approximately a maximum of one second. The preferred duration of a planning or processing unit for English speakers is likely to be 350 ms to 400 ms, which is approximately the mean duration of the two syllable foot, which is also the most frequently occuring one in English. In other words, the system is likely to function efficiently in processing and planning units that meet a certain temporal limit.

Although this hypothesis of temporal constraints for processing is reasonably logical, further empirical evidence is needed to support this notion. For instance, evidence on preferred duration for planning and processing speech units for speakers of different languages needs to be established. The questions here are whether or not the unit for processing is universally constrained temporally or is the speaker of a given language somehow conditioned to plan and process a unit of a certain magnitude more efficiently than others? The temporal limits for planning and processing speech units are likely to be dictated by the structure of the language speakers and listeners use.

Although several studies have referred to processing limits, most often they have used number of syllables to mark the upper bounds. While this information has been beneficial, we also need to know whether these syllables belong to a rhythmic unit or whether the maximum temporal capacity will permit planning and processing one or more rhythmic units without undue latency.

The evidence presented so far clearly refutes the notion of production isochrony. However, it seems critical that the interstress intervals fall within a critical duration, possibly to meet the demands of the processing and production mechanisms

In the following sections, more evidence will be presented in favor of rhythmic units as units of temporal planning. Furthermore, the evidence of certain timing rules operating in relation to rate and rhythm will be presented.

B. Temporal Regularities

One of the most significant findings of the present study is that both stressed vowels and the first unstressed vowels in the rhythmic units showed temporal compression as a function of foot size, thus providing evidence in support of metric feet as units of planning.

The temporal compression of stressed and first unstressed vowel resulted in significant differences between foot sizes for both stutterers and normals. The temporal compression for stressed vowels as a function of number of syllables yet to be articulated, corroborates with several earlier production studies on English (e.g., Port, 1981; Klatt, 1975; Oller, 1973; and Lehiste, 1972), Dutch (Nooteboom, 1972), and Swedish (Lindblom and Rapp, 1973). Nooteboom (1973, 1975) in a perceptual experiment using Dutch speakers showed that the speakers' preferred durations for vowels reduced as a function of number of syllables yet to be produced in a word. He used synthetic speech and a method of adjustments to obtain preferred durational measurements. Further, these preferred durations corresponded with the measured durations obtained from the speakers' production samples.

The results of the present study on the temporal compression of stressed vowels has greater import for English than those of the earlier studies, particularly those reported by Nooteboom (1973, 1975). The present data is based on measurements made on natural speech texts and larger number of subjects as opposed to the use of nonsense words produced by three speakers in Nooteboom's study. Additionally, in the present study, the rhythmic units were not confined to polysyllabic words, but they crossed word boundaries in which function words were included as well.

The present data on temporal compression not only confirms the existing knowledge on stressed vowel, it also provides empirical evidence of other timing regularities in natural connected speech. This consistency of the present findings with earlier studies indirectly indicates a single mechanism of temporal organization of speech for different contexts or modes. This evidence contradicts Harris and Umeda's(1974) contention that speech is organized differently for different modes.

Besides this compression of stressed vowel, both normals and stutterers showed temporal compression of the first unstressed vowel and the intervowel interval as a

function of foot size. This observation which has not been reported in empirical studies so far, further supports the notion of rhythmic units as unit of temporal organization.

Although both stutterers and normals showed significant compression of stressed vowels across foot sizes, both groups differed in the magnitude of compression that occurred across the foot sizes. The stressed vowel decreased in duration by 38.3% for normals and by 33.7% for stutterers. This lesser degree of compression for stutterers corresponds with their consistent slower than normal speaking rates.

For normal speakers, the compression of stressed vowels was observed for rhythmic units in sentences. The extent of compression from disyllable to six syllable foot was about 17.4% This lesser degree of compression can be explained by the fact that in these sentences the stressed vowel in "credit" was measured in feet of various sizes. A given vowel will perhaps compress only up to a certain degree. In further support of this contention, it was observed that the extent of compression of first unstressed vowels in rhythmic units in sentences when compared to units in passages was again less. While for connected text, the first unstressed vowel reduced by 19.6% for normals, and 9.8% for stutterers, (from F2 to F5) the compression for the first unstressed vowels for units in RUSS was only 11.1% from F2 to F6.

These observations support Klatt's (1976) maximum compressibility theory. According to this theory, all vowels compress up to a certain limit and this limit depends on the minimal inherent durations of the vowels. Since the unstressed vowels are relatively shorter than the stressed vowels, the extent to which they can compress without affecting perception is limited. In fact, when the F values for foot size (from the ANOVA) are compared for IVI, SV, and 1USV, the highest F value was noted for SV ($F=39.79$, $df=4$, $p<0.001$). The next highest was IVI ($F=30.54$, $df=4$, $p<0.001$), and the lowest F value was obtained for the 1USV ($F=11.46$, $df=4$, $p<0.001$). This ranking of F values suggests that the compression is the greatest for the stressed vowel, least for the first unstressed vowel, and that the extent of compression for the intervowel interval falls between the two.

This finding on the difference in the magnitude of compression, particularly for the stressed vowel and the first unstressed vowel, further supports the theory of maximum compressibility. Somewhat in contradiction is Lea's (1976a) observation that with increase

in rate, although all vowels and syllabic nuclei are shortened, the durations of unstressed vowels decrease more than those of stressed vowels. This implies a greater temporal constancy of stresed syllables, thereby allowing the unstressed vowels to vary in order to alter the rate of speech. In fact, the total unstressed vowels show temporal expansion as a function of foot size (Fig. 4.10). For this trend to occur, despite temporal compression of the 1USV, one or more unstressed vowel following the 1USV should show temporal expansion. If compressions had occurred in other unstressed vowels, then the overall greater than linear trend would not be seen. Further ANOVA on the data on total unstressed vowel durations showed significant differences between stutterers and normals, which become progressively larger in a similar manner as for the interstress interval. Stutterers in both instances showed considerably longer durations with increasing foot sizes when compared to normals. This statistically significant group by foot size interaction is demonstrated by the widening of the plots for the two groups as a function of foot size. This interaction is absent for the first unstressed vowels and stressed vowel durations. This is illustrated by the parallel plots in figures 4.5 and 4.9 for the stressed vowel and unstressed vowels, respectively. This parallel trend suggests that stutterers are able to employ certain rules of language that operate to control the temporal regularities just like normal English speakers.

Temporal compression and expansion of specific components as a means of rate control could possibly be language specific timing rules. The interactions of these temporal regularities in rate control, the motivations by which they are governed, and the limitations within which they operate, will be the objects of discussion of the next section.

C. Rate

From several earlier studies it is clear that the duration of vowels are reduced with increase in rate of speech (Gay, 1978, 1981). As mentioned earlier, the present data shows that the time per syllable decreased with increasing foot size for both stutterers and normals up to three syllable unit. This rate increase, however, reaches a plateau from from F3 to F4 and then rate reduction occurs for the longer units (Fig. 4.2). This observation can now be related to the observations on compression of stressed vowel, first unstressed vowels, and intervowel interval. While the rate increase is achieved by the

compression of the IVI, SV and 1USV, the effect of compression appears to be counteracted by the temporal expansion of the TUSV duration. An alternate speculation is that, since the duration of unstressed vowels are relatively shorter compared to SV and IVI, compression of all USVs may not be possible due to perceptual and articulatory constraints. Thus, the unstressed vowels by the virtue of their smaller durations temporally expand, while the other components with relatively longer durations show temporal compression. It is further speculated that the selection of components for temporal compression and expansion are governed by language specific rules.

The stabilization of rate that is seen between F3 and F4 corresponds with the slight increase in duration of SV and 1USV for F3, and with increased compression for IVI. Thus selective compression and expansion of components results in rate stabilization. This observation is substantiated by the data on RUSS, in which temporal compression of SV and 1USV occurs as a function of foot size. Therefore, the spike seen for SV and 1USV at F3 for the principal experiment is considered a deviation from the regularities of temporal organization. Moreover, for RUSS, despite the greater than linear increase for IVI, the rate remains almost constant for units of all sizes. Thus stabilization of rate seems to occur through temporal compensations between components within a rhythmic unit. Since the temporal compression of SV and 1USV seem to be consistenly present for all speakers, both in the principal and the auxiliary experiments, the compression of these components may be considered as evidence of temporal regularities of English. The compression of IVI, on the other hand, is perhaps secondary and may occur only if compression of the "primary compression" components have attained maximum compressibility. At this point, this notion of the existence of primary and secondary compression components is merely speculative. It is also speculated that possibly, for speakers of a given language, compression of certain components may be more natural than others.

Yet another observation that supports the theory of maximum compressibility and the notion of primary components of compression comes from the data on normals for RUSS. For F6 temporal compression of the total unstressed vowel is seen in addition to the compression of SV and 1USV, while the IVI continued to show greater than linear increase. It appears that if the components that regularly compress achieve maximum compression, then the other components in the unit are likely to compress, so that the

duration of a planned unit will not exceed the processing limits.

While stutterers and normals seem to use similar strategies for rate increase and rate stabilization, they appear to differ in their rate reduction strategies. Normals achieved this rate reduction through increasing USV durations, at the same time maintaining the temporal compression of IVI, SV and 1USV. Stutterers, on the other hand, achieved rate reduction through increased USV and IVI, while still showing temporal compression of SV and 1USV. This deviation in temporal regularities for stutterers for the longer unit is perhaps due to the fact that the five syllable unit, for which rate reduction occurred, is not a frequently occuring unit, and perhaps the unfamiliarity of the rhythmic structure imposes a greater demand in terms of articulatory planning for stutterers. In general, the differences between stutterers and normals were the greatest for F5 for all the components in a rhythmic unit. Stutterers therefore show evidence of having difficulty planning and/or executing rhythmic units longer than four syllables. This deviance from the the temporal regularities also results in the discrepancy for F5 between stutterers and normals. This issue will be discussed in detail in the next section.

This observation on selective temporal compression and expansion is an important one in understanding the mechanism of rate control. It seems that changes in rate does not result in a linear transformation of all components of a planned unit. This finding concurs with Gay's findings on mechanism of rate changes.

According to Gay (1977, 1978, 1981), changes in rate do not occur as simple changes in duration and spacing of motor commands, but rather a more complex reorganization of motor activity of the muscles in question occur. Rate-induced nonlinearity was observed between consonant and vowel durations at the muscle activity level (Gay, 1978); the consonant durations were more resistant to change than vowel durations. Although more work needs to be done to fully understand the physiological intricacies of rate control, the speculation is that rate induced complex reorganization of muscle activity occurs in order to maintain the relative timing betwen speech components.

This consistency between Gay's findings and the present study is striking in view of the fact that Gay had his subjects intentionally speak at faster rates, whereas in the present study, the rate increase was observed with increase in the size of a planned unit as a natural consequence, possibly, to meet the temporal processing constraints.

Further, the data from stutterers showing lesser degree of compression and consistent slower than normal rate indicates that the magnitude of compression is related to the extent of rate increase. That is, the faster the rate a speaker intends to use, the greater will be the compression of the selected components. However, as noted in the above discussion, there seems to be a maximum limit beyond which compression may not occur. This limit is likely to be associated with the maximum rate a speaker could achieve within the restrictions set by processing and production mechanisms Thus, from the above discussion, it is suggested that, to meet the demands of a temporal processing mechanism, rate control strategies come into play. These strategies are certain consistent timing rules that result in selective temporal compression and expansion, and together they regulate the rate of speech. It is further speculated that the rules for temporal compression and expansion are language specific rules, which appears to be related to other timing rules such as the relative timing. The discussion of this relationship between rate and relative timing will be focused in the next section.

D. Relative Timing

One of the most significant findings in this study is on relative timing between components of the rhythmic unit. Despite the differences between stutterers and normals in terms of rate and absolute durations of individual components, both groups had similar ratios between intervowel interval to total vowel duration and stressed vowel to unstressed vowel duration for a given sized unit, with the exception of the five syllable unit (Fig. 4.16a,b). Interestingly, for RUSS, the ratios between intervowel interval to total vowel duration were almost constant. This temporal invariance corresponds with the almost constant rate noted for RUSS across rhythmic units of all sizes. This observation on relative timing in the auxiliary experiment further confirms the significance of relative timing for speakers of English.

The similarities noted for stutterers and normals on relative timing indicates that this group of stutterers were similar to normals in the temporal organization of rhythmic units. Furthermore, it appears that the lesser degree of compression and slower than normal rates noted for stutterers facilitate the maintenance of a critical relative timing between components. For stutterers, it may be possible to maintain this critical relative

timing and fluency at a certain rate, which is likely to be a rate slower than normal. However, if additional demands are placed in terms of articulatory planning, stutterers are likely to show deviations of temporal regularities, which in turn will affect the relative timing or the rhythm. For instance, for the longest unit (F5), both stutterers and normals showed rate reduction, and normals achieved this without altering the temporal regularities. That is, normals consistently showed temporal compression and expansion of specified components, whereas stutterers showed deviations from temporal regularities. It appears that stutterers usually have to compromise on rate to maintain fluency and rhythm, and further, if greater demands are placed on articulatory planning, they may have to compromise on both rate and rhythm in order to maintain fluency.

The data on stutterers showing similarities in the internal organization of rhythmic units have shed more light on how normal speakers maintain the rhythm of English. It is also suggested that the relative timing of speech components of a unit that determines the rhythm of a language.

Without the data on stutterers and the data on the RUSS, from the auxiliary experiment, the ratios for each rhythmic unit for normals alone would have been merely descriptive.

The present data on relative timing is consistent with Port's finding (1981), that a constant ratio exists between stressed vowel duration and the following consonant. The ratio changing primarily with the voicing value of the consonant. These results further corroborate with some studies on muscle activities. In a series of studies (Kelso, Tuller and Harris, 1981; Tuller and Harris, 1980; Tuller, Harris and Kelso, 1981; Tuller, Kelso and Harris, 1981), the Haskins research group explored the temporal relations of articulatory events using electromyographic measures and showed that temporal relations among articulators remain constant over changes in stress and speaking rate, while the individual gestures themselves changed. They stated that specifically, the relative timing of consonant activity for flanking vowels remained constant over suprasegmental changes. These observations were, however, based on very restricted set of nonsense syllables. These researchers found that their results on articulatory movements were compatible with the preservation of relative timing over changes in magnitude of movements over different muscle groups such as those involved in writing and locomotion.

Perceptual experiments also suggest that relative timing, and not absolute duration that is important at the segmental level in distinguishing phonetic boundaries in relation to rate of speech (Rakerd, Verbrugge and Shankweiler, 1980; Miller and Liberman, 1979). The significance of relative durations has been reported on Japanese by Port (1980), who also observed that the relative constant sum of segment durations is critical and that temporal compression extends across several syllables. In essence, Port noted that both the sum of morae and the individual segments have a target duration.

A synthesis of the issues discussed so far shows that it is important for speakers of English to maintain a critical ratio between components of a given planned unit. It is hypothesized that this relative timing determines the rhythm of a language, in this instance English. Triggered by the temporal limits of processing, changes in rate occur. The mechanism of rate change, however, seems to be governed by the constraints of processing and production mechanisms and by certain relative timing rules. Thus by selective temporal compression and expansion of the speech components, rate control is achieved without compromising the rhythm.

E. Implications for Stutterers

For stutterers, this seemingly complex reorganization that occurs during rate changes has greater implications.

The two most popular therapeutic techniques used with stutterers to facilitate fluency are syllable timed speech and syllable prolongation. Both these techniques facilitate fluency by inducing a slow rate of speech (e.g., Perkins, Bell, Johnson, 1979; Ingham and Andrews, 1973; Boberg, 1976 and others). From our present knowledge on the significance of relative durations of intervowel intervals and vowel durations, it is clear that syllable prolongation is likely to alter the rhythm of speech, although these techniques facilitate fluency. Stutterers must therefore effectively control their rates so that both fluency and relative timing of components would be maintained. While stutterers who have undergone treatment may have learned strategies for rate control, it is not known whether their fluent utterances prior to treatment will show any tendency to maintain the critical temporal relations for a given unit.

Perkins (1979) has addressed the issue of the effect of slow rate of speech on the "rhythm" of stutterers' speech when they are trained to prolong all the syllables equally. He noted that the prosodic pattern of speech is altered. Subsequently, when the stutterers' accelerate their rate, the disrupted prosody is maintained. As a result a "fast monotony" prevails. In order to offset these effects of syllable prolongations and slow rates of speech, stutterers were trained to prolong only the "stressed" syllables about two seconds each and subsequently they increased the rate by shortening the duration of stressed syllables, all the while touching the unstressed syllables lightly. Perkins noted that "a trade off seems to exist between rhythm and other dimensions with which fluency is maintained. The stronger the rhythm pattern, the more the speaker can survive hard vocal attacks, rapid rate, breaks in the breath stream..."(p.107). This statement is vague and it is not clear as to what Perkins means by "strong rhythm pattern".

The effect on the rhythm of speech when stressed syllables alone are prolonged is still not known. While prolonging a single syllable as opposed to all the syllables may result in speech that is more acceptable, it seems rather incompatible with the occurrence of temporal compression of stressed vowels in natural speech as a function of length of interstress intervals. In the light of our present knowledge on temporal compression and expansion, it may be beneficial to practice stress contrasts by systematically varying durations in the context of rhythmic units of varying sizes. However, the incorporation of stress contrasts into the training program may not be effective at very slow speaking rates, such as 60 syllables per minute (e.g., Boberg, 1976, 1981), because listeners are not likely to integrate stress contrasts, and thus the rhythm pattern, if temporal events occurred at one second interval or more. The present data nevertheless indicates that stutterers maintain fluency and rhythm at slower than normal rates. Therefore, training in stress contrasts could perhaps be introduced when stutterers achieve a certain rate at which the balance between fluency and rhythm could be achieved and maintained. Again, it is not unreasonable to expect stutterers to use slower than normal rates in facilitating maintenance of fluency (Boberg, 1981), as the present data shows that at slower than normal rates, fluency and rhythm could be maintained. However, we need to obtain data from perceptual experiments using normal speakers in order to arrive at an optimal rate for stutterers.

The different techniques that result in rate reduction for stutterers may in fact result in fluent speech that differ in the temporal domain.

At least for some stutterers, the complex reorganization that ocurrs with rate reduction involving reorganization of muscle activities (Gay, 1981) may be difficult to achieve. On the other hand, there may be other fluency inducing techniques such as shadowing or choral reading which facilitate a slower rate of speech without affecting the temporal configuration of the components of a unit. Wingate (1982) in a recent article examined the fluency inducing conditions using spectrographic tracings. The four conditions were talking to rhythm, choral reading, shadowing, and singing. From a qualitative comparison, he inferred that the tracings under conditions of choral reading and shadowing did not show any consistent pattern of changes in duration and amplitude. Whereas, speech to a rhythm showed considerable variation in the length of syllables and intervals in between. However, Wingate pointed out that under all these conditions there was reduced variation of the intonation pattern, resulting in changes in prosodic pattern.

Although in the present study, the primary concern has been on temporal organization of speech and its effect on the "rhythm", the other features of prosody, pitch, and amplitude, are by no means implied to be less important. Nevertheless, it is well known that facilitation of fluency is most effective when segmental durations are increased. This consequently results in rate reduction and stress modulation (Wingate, 1976). Wingate has further stated that "a substantial contribution of slowing down is to facilitate a focus on prosody" (Wingate, 1982). Speech heard and spoken at a considerably reduced rate will undoubtedly draw attention to speech prosody. If, however, normal prosody and fluency have to be maintained at the same time, a variety of strategies may be used within a therapeutic program. For instance, rate reduction strategies which facilitate fluency should also be followed by practice in stress contrasts. The rhythmic units of varying sizes starting from the disyllable (which occurs most frequently) units will not only provide contexts for stress contrasts, they also provide conditions that will naturally trigger modulation of rate and maintenance of relative timing between components. The use of rhythmic units of varying sizes will also provide systematic practice for planning units of varying length.

Furthermore, rhythmic speech units could be potentially used as tools to measure variations on rate and rhythm, by obtaining measures of interstress intervals for rate, and relative timing between components as a measure of rhythm. The critical relative timing between components will be influenced by the nature of rate reduction strategies empolyed. Syllable prolongation or talking to a rhythm or syllable timing are more likely to disrupt this critical timing between components, consequently affecting the rhythm of speech. Then, by restoring normal trends in rate variation for rhythmic units, it may be possible to restore the critical timing between components.

One rate reduction strategy that should be considered is the use of durational cues for establishing stress contrasts within the context of rhythmic units. From the results of the present study, it seems reasonable to expect the maintenance of fluency, rhythm, and rate, at least for rhythmic units that are relatively more frequent in English. At this point, these notions on therapeutic strategies for the maintenance of fluency, rate, and rhythm are speculative and needs to be substantiated by future research.

It is likely that, while some stutterers may be able to maintain a close to normal rhythm, fluency, and rate, at least for shorter temporal units, there may be some stutterers for whom this balance may be difficult to achieve.

This point is further clarified upon scrutiny of the values obtained from individual subjects for SVs and the 1USVs. For the first unstressed vowels, three subjects in the group of stutterers differed from the group trend. This suggests that these subjects did not effectively use rate control strategies or did not plan their units in terms of rhythmic units. The latter speculation is rejected because these subjects did show temporal compression of SV as a function of foot size. Therefore, it is more likely that they failed to use the mechanism of rate control as effectively as others. For stressed vowels, one normal subject and one stutterer differed from their group trends. These two subjects showed a slight increase in the duration of stressed vowel for the five syllable unit instead of compression. The five syllable unit as indicated earlier is not a frequently occuring unit in English and therefore the inconsistency shown by these two subjects may be due to unfamiliarity in temporally planning longer units.

It is relevant here to briefly reexamine a study done by Shapiro (1970) which was recently reviewed by Wingate (1982). Shapiro reportedly used 15 male and 15 female

stutterers, and used intensity as a measure for comparing stress patterns of several brief utterances of stutterers and normal speakers. The curve for each utterance was plotted with amplitude in the x axis and the time in the y axis. The results showed that stutterers showed increased amplitude for the initial stress, but subsequently the curves showed a rapid decay. Also, temporally, the first stressed pulse was influenced by the length of the intended utterance.

On examining the utterances used by Shapiro (seen in Wingate, 1982) in terms of the rhythmic units, as defined in the present study, the longer utterances (from four to five syllables) are rhythmically different from the three syllable utterances. Examples of four and five syllable utterances are, "Thug has six legs" and "The cat's name is Tom". A three syllable utterance is, for example, "Rex chased Tom". While the three syllable utterances have three successive stresses, the four syllable utterance has an alternating stress pattern for the first three syllables, and the last two syllables are successively stressed. The five syllable utterances begin with an unstressed syllable. Wingate noted that the curves for the three syllable utterances for stutterers were similar to normals, and that the differences in curves were more apparent for the four and the five syllable utterances. A reinterpretaion of these findings in terms of rhythmic units as used in the present study would suggest that the equal stressedness that is required for the three syllable utterances in question is likely to result in isochronous timing, and therefore would be more similar to syllable timed speech, which stutterers would have practiced in their therapeutic programs The increased amplitude and temporal displacement for longer utterances seems to be due to imposing stress on the initial syllable which should in fact be unstressed. This indicates a lack of variation in stress contrasts, and is likely to be evident temporally. This in turn will result in deviations from the normal trend in terms of temporal compression, rate, relative timing of components, and thus, the overall rhythm of speech.

F. Implications for a Timing Model

The issue discussed so far should be viewed in the light of some of the existing models of speech timing to explain temporal organization of rhythmic units. The significant findings on temporal compression, expansion, and rate within rhythmic units strongly support the notion that temporal organization of speech occurs in terms of rhythmic units,

thus supporting an open loop, (comb model) system of Kozhevnikov and Chistovich, (1965), as opposed to a closed loop (chain model) system. Although Kozhevnikov and Chistovich based their model on their findings on Russian, the results of the present study are very similar to those reported by the Russian researchers. In particular, variations in durations of individual components occurred within the unit, but there seemed to be a certain temporal invariance in terms of relative timing between components. The similarities between stutterers and normals for relative timing for a given sized unit, and in particular, the temporal invariance seen for normal speakers for RUSS, support the notion that successive syllables within a rhythmic unit are preplanned.

Although these findings are in support of an open loop model, they do not support the isochrony hypothesis according to which interstress intervals would be of equal duration. In contrast, temporal compression was seen in some components as a function of foot size.

Besides providing substantial evidence in support of the comb model, the findings of the present study are significant in understanding how rate and rhythm are regulated within rhythmic units. The interactions between the temporal regularities observed within the rhythmic units led to the consrtuction of a possible model of speech timing.

A possible model of speech timing is illustrated diagramatically in Fig. 5.1. This model is mainly proposed to explain the rate control mechanism that was observed, and in the hope of spurring experimental interest in rate and rhythm.

According to this model, the unit of planning is a rhythmic unit, which to some extent is determined by the production and processing constraints, which also influence the structure of the language. The size of the unit planned, and the output should also meet the limits set by the processing and production mechanisms. Therefore, for longer units, rate increases occur and this is governed by certain speech timing rules, which regulate the compression of selected components. However, due to the limitations imposed by the production and processing mechanisms, the magnitude of compression is regulated. The effects of compression are also counteracted by the temporal expansion of selected components. This interactions between temporal compression and expansion governed by relative timing rules result in rate modulation. These three timing rules, i.e., selective compression, selective expansion, and relative timing are considered language specific

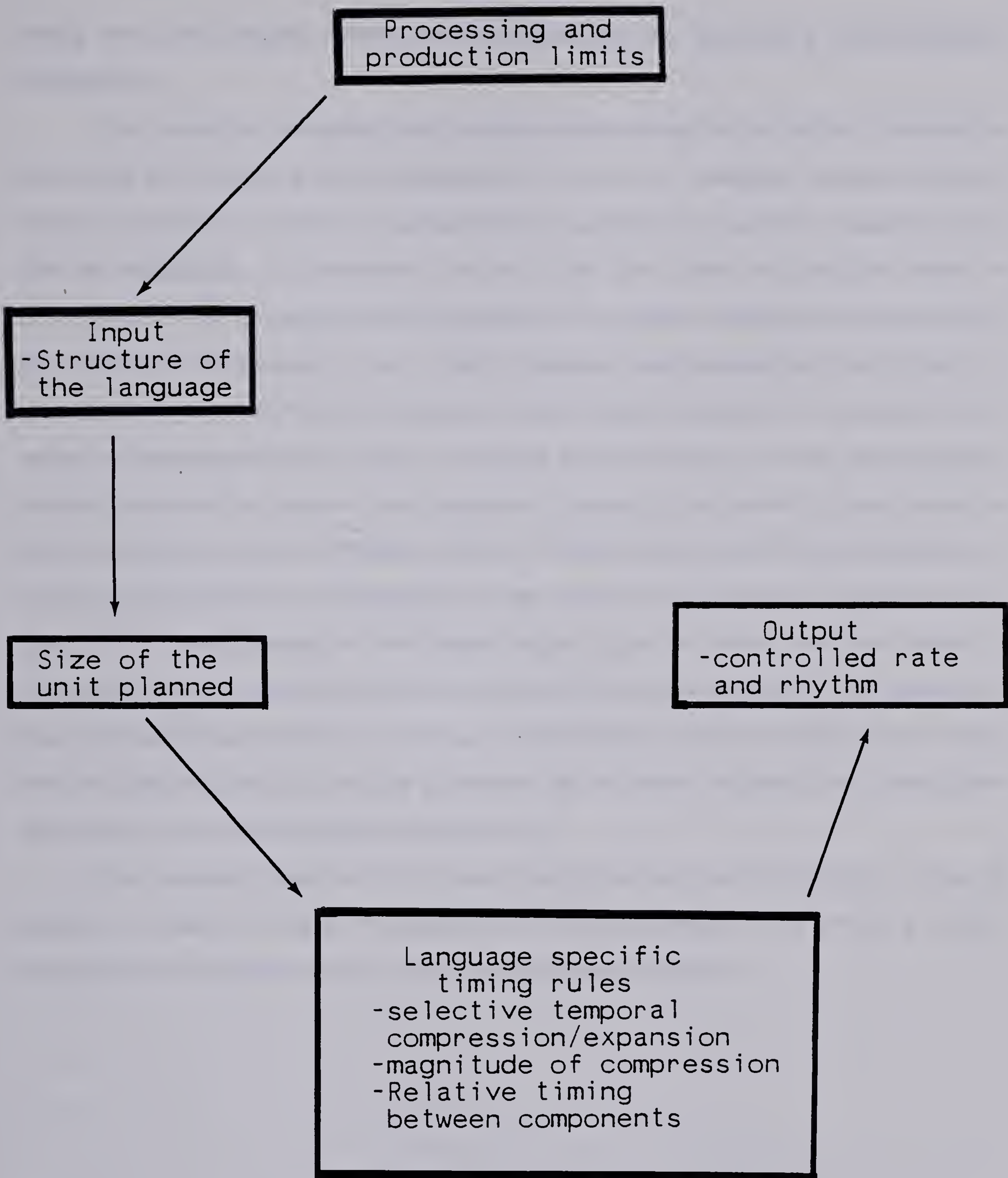

Figure 5.1 A possible model of speech timing.

timing rules that operate within the constraints of the processing and production mechanisms

This model has similarities with Lashley's model in that, various factors illustrated in the model are interacting and interdependent. The role of feedback, however, still not known. In particular, we need to seek answers to questions such as how a speaker knows that the magnitude of compression and thus rate falls within the temporal limits of processing, or is it the physiological limitations of the speech mechanism that determines the extent of compression? Port (1981) maintains that physiological restrictions on articulation do not manifest themselves as a kind of output constraint. He argues that the extent of compression he found in his study are not likely to be the physiologically minimum duration that speakers are capable of producing. The extent of compression is then, perhaps governed by language specific relative timing rules. Finally the question is, what guides the speaker in maintaining a certain relative timing between components of a given unit? The speculation is that these language specific timing rules are similar to phonological rules a speaker has acquired as part of language acquisition. The feedback is then external and comes from the listener. If the listener indicates processing difficulties, then the speaker is likely to choose a different set of words, rephrase, and thereby alter the rhythm of a unit and possibly the rate as well.

This possible model is by no means complete, and does not intend to cover all aspects of speech timing in the regulation of rate and rhythm. It is merely a skeletal framework for a potential model, which requires future validation.

VI. CONCLUSIONS AND IMPLICATIONS

In this chapter the conclusions of this study and the implications it holds for research will be presented.

A. Conclusions

The present research showed no evidence in support of production isochrony, although the results supported the notion the speech units are preplanned in terms of rhythmic units (interstress intervals). Thus supporting an open model of speech timing , specifically the comb model, as opposed to a closed loop model.

In order to explain the various interacting and interdependent factors observed within the rhythmic units in this study, a possible model of speech timing is proposed.

According to this model, it is the temporal limits of processing that determine the size of the unit planned, thereby, motivating rate increases. However, this rate increase reaches a plateau, possibly due to the limitations of the production and processing mechanisms. While the temporal compression of IVI, SV, and 1USV results in rate increase, this compression is counteracted by the temporal expansion of the unstressed vowels. This compression and expansion of selected components results in the stabilization of rate. For normal speakers, any rate decrease seem to result from temporal expansion of selected components rather than the reduction in compression, thus suggesting that certain rules operate within a planned unit. Moreover, the rate control mechanism also interacts with certain relative timing rules that operate to maintain a critical relative timing between components. Thus, changes in rate do not occur as linear transformation of all the components within a planned unit.

It is speculated that the selective compression and expansion of components and the relative timing are specific timing rules that regulate rate and rhythm of speech. In essence, the rate control mechanism then, will not only operate within the limits set by the production and perception mechanisms, but also by the dictates of certain language specific relative timing rules.

The similarities in the operation of these timing rules for both stutterers and normals and the observations from the auxiliary experiment further confirm that selective

compression, expansion, and relative timing are speech timing rules of English and that these rules interact with each other to produce the desired rate and rhythm.

Although the group of stutterers used in this study showed temporal regularities similar to normals, the breakdown in temporal regularities that occurred for the longer units for stutterers suggests that stutterers are likely to have greater difficulty planning and executing longer units while maintaining fluency, desired rate, and rhythm. Stutterers perhaps have to compromise on rate and relative timing, i.e rhythm, in order to maintain fluency.

The three factors, temporal compression, expansion, and relative timing that have been identified as parameters of speech timing rules, offer some specific parameters for the study of rate and rhythm. Future investigations are warranted to study the interactions of factors governing rate and rhythm both in stutterers and in normal speakers. For instance, the relationship between coarticulation and relative timing needs to be examined.

Furthermore, since the present study has provided evidence for rhythmic units as units of temporal planning, there is a great potential for the use of rhythmic units with stutterers and other prosodic disorders for facilitating fluency and normal rhythm. These issues which have significant clinical implications need to explored systematically.

Finally, the rate control mechanism described here was designed to explain the observations of interactions and interdependencies of components within rhythmic units. This is merely a skeletal framework for a potential model of speech timing and needs to be substantiated by future research.

B. Research Implications

The present study has raised some interesting speculations regarding the rhythm of speech in normal speakers and stutterers alike. An attempt is made to enumerate all the possible issues that warrant future investigation, although some of these issues have been mentioned in the course of the discussion.

Temporal Issues in Normal Speech

Timing model: The possible model described in this study to explain regulation of rate and rhythm should be substantiated through perception studies as well. The relevance of temporal compression, expansion and relative timing can all be studied through careful manipulation of the speech signals and listeners' judgement can be obtained on the temporally modified signals.

Unit of planning: Some of the possible studies in understanding interstress interval as a unit of planning and/or processing in normal speakers are discussed in this section.

Although, in this study, evidence was presented in support of rhythmic unit as a unit of planning it was also noted that temporal processing constraints are likely to determine the size of the rhythmic units in a language, the duration of the most frequently occuring foot size is likely to be the preferred duration for speakers of a given language. This notion is purely speculative and we need to seek empirical evidence to find out whether or not the unit for processing is universally constrained temporally, or whether a speaker of a given language is somehow conditioned to plan and produce a unit of a certain magnitude more efficiently than others. In other words, do speakers of different languages have different preferred durations for planning and producing a speech unit?

Perceptually, the significance of the rhythmic unit as a unit of processing can be determined using an experimental paradigm similar to that used by Kozhevnikov and Chistovich (1965). These researchers reported on listeners' performance in recognizing filtered sentences as a function of number of syllables. A study of listeners' performance on recognition of filtered speech by controlling for number of syllables and for the size of the rhythmic units, will reveal whether the rhythmic unit or the temporal processing limit is critical in determining the unit of processing. It is possible that significant interactions of limits in processing and the size of the rhythmic units are likely to occur. It is also possible that longer rhythmic units, despite their size, may still be recognized by listeners with greater accuracy than longer utterances made up of several syllables, of equal length. Such a finding would then confirm the importance of rhythmic units in processing and planning, perhaps due to their stress syllables that carry high information value.

Temporal compression: An important observation that led to the hypothesis of rhythmic

unit as a unit of planning was the temporal compression of SV, 1USV, and IVI as a function of foot size. At the same time it was also observed that the rate of speech also increased as a function of foot size up to a certain point. The relation between magnitude of compression and rate needs to be investigated. The question is, supposing the stressed vowel and the first unstressed vowel which normally seem to undergo temporal compression attain a limit and cannot undergo compression any further, do other components of speech in a rhythmic unit undergo temporal compression to achieve a target rate? Apart from the theoretical interest in answering such a question, there are some practical applications. For instance, a synthesized unit of speech will perhaps be judged as being more natural or acceptable if it is compressed in accordance with the natural rules, compared to the overall compression of a speech unit. This question is particularly important in the light of our finding with regard to critical timing relations between components in a rhythmic unit

Relative timing: The significance of relative timing needs to be verified through perceptual experiments. An useful experimental paradigm would be to obtain listener judgements of speech that have altered temporal ratios between its components.

Another speculation that grew out of the finding on critical relative timing is that it is this certain predetermined durational ratio between the components of a speech unit that determines the rhythm of a language. Using speakers of different languages, we can verify whether or not speakers maintain similar ratios for nonsense units regardless of their relative timing in their respective languages. If they maintain similar ratios regardless of their languages, then relative timing is likely to be determined by the phonological make up of a production unit. On the other hand, if speakers of different languages show critical timing within components of nonsense unit similar to the timing relations in their native tongue, then we could infer that the critical timing determines the rhythm of a language, which speakers are likely to carry over to nonsense units as well.

The observation on relative timing of components of a speech unit has stirred yet another possibility for future investigation. The lack of "naturalness" of synthesized speech comes from the concatenation of speech segments. If a provision is made to adjust the syllabic durations, then by altering the durations of syllables, a critical relative timing could

be established which in turn is likely to result in synthesized speech utterances that are likely to resemble natural speech. This notion of adjusting durations to match an inner temporal criteria is not new. Nooteboom (1975) used a method of adjustments using synthesized speech segments in a perceptual experiment. He asked subjects to adjust the duration of synthesized vowels in a word in such a way that the word as a whole sounded as natural as possible. A desired stimulus was synthesized repeatedly and the duration of one acoustic segment of the word was contiuously adjusted by means of a knob. A very important application of this duration adjustment feature would be for communication aids that use synthesized speech. With our present findings on the significance of relative timing between components, by adjusting the durations of the components of speech, it would be possible to produce utterances which would perhaps have a rhythm that simulates natural speech. While it may not be practical to expect users of communication aids to have the linguistic intuition or the physical capabilities to make these temporal adjustments, it is, however, possible for trained clinicians to make these durational adjustments in these aids that have provision for storing programmed utterances.

Research Implications on Stuttering and Rhythm

Frequency of stuttering: Several subjects were eliminated because of the non availability of sufficient number of fluent samples in all the target units. Also, several longer units were eliminated for lack of sufficient number of subjects fluent in these longer target items Of particular interest would be the reexamination of the speech samples obtained from the subjects in the present study and determine the frequency of stuttering as a function of foot size. If the frequency of stuttering is in fact greater for larger units, then it is likely that the use of a more familiar (or the preferred) rhythmic pattern will result in ease of production. This issue directly raises the question of effects of adaptation on the speech of stutterers.

Until now, it is believed that through practice and familiarity of the phonetic contexts, fluency could be expected in stutterers. However, if stutterers are indeed relatively more fluent on certain rhythmic pattern than others, then the question is whether the effect of adaptation observed in stutterers is in fact due to familiarity of rhythmic

pattern. This question can be easily verified by manipulating the phonetic contexts and the stress pattern independently.

Rate and Relative timing: The present study shows that, at slower than normal rates stutterers can maintain the rhythm of speech. We need to obtain data from perceptual experiments, using normal speakers, to determine an optimal rate at which stress contrasts can be perceived and integrated perceptually as rhythmic patterns. Prior to treatment stutterers seem to have a faster rate of speech compared to normals, hence the rationale for teaching strategies to reduce their rate of speech in order to induce fluency. It would be interesting to investigate whether stutterers use faster rate of speech to maintain the relative timing between components.

In the present study, with the exception of two subjects, all the other stutterers had undergone treatment. Although these two subjects did not differ from the group in any significant manner, in order to understand whether the rhythm of stutterers' speech is different from normals (or disrupted), a replication of the present study with stutterers who have not undergone treatment would be in order. Such a study will also verify whether stuttering is indeed a "disorder of rhythm" as described by several researchers in the field of stuttering.

In addition, the investigation of "rhythm" in the speech of stutterers from different therapeutic programs will assist in the identification of these strategies that will facilitate fluency with no or minimal effect on the rhythm of speech.

Lastly, stutterers' fluent utterances have been judged by listeners (e.g., Prosek and Runyan, 1982) and found to be distinguishable from normal fluent utterances. In view of the findings of the present study, it would be valuable to correlate listener judgements of "rhythm" on fluent speech of stutterers from various treatment programs with measurements on relative durations of components within rhythmic units. In other words, the perceptual ratings on rhythm should be correlated with objective acoustical measurements of duration.

BIBLIOGRAPHY

Abercrombie, D. 1964. Syllable quantity and enclictics in English. In *In Honour of Daniel Jones.* Eds. D.B.Fry, N.C.Scott and J.L.M. Trim. London: Longmans.

Abercrombie, D. 1965. A Phonetician's view of verse structure. In *Studies in Phonetics and Linguistics.* London: Oxford University Press, 16–25.

Abercrombie, D. 1967. *Elements of general phonetics.* Chicago: Aldine–Atherton.

Adams, M.R. and Hutchinson, J. 1974. The effects of three levels of auditory masking in selected vocal characteristics and the frequency of dysfluency of adult stutterers. *Journal of Speech and Hearing Research 17:* 682–687.

Adams, M.R., Runyan,C. and Mallard, A.R. 1975. Airflow characteristics of the speech of stutterers and non stutterers. *Journal of Fluency Disorders 1:* 3–12.

Adams, M.R. and Hayden, P. 1976. The ability of stutterers to initiate and terminate phonation of an isolated vowel. *Journal of Speech and Hearing Research 19:* 290–296.

Adams, M.R. and Runyan, C.M. 1981. Stuttering and Fluency: Exclusive events or points on a continuum. *Journal of Fluency Disorders 6:* 197–218.

Agnello, J. and Wingate, M.E. 1971. Air pressure and formants of stutterers and non stutterers. *ASHA convention paper:* Chicago.

Agnello, J. 1974. Laryngeal and articulatory dynamics of disfluency interpreted within a vocal tract model. In *Vocal Tract Dynamics and Fluency.* M. Webster and L.Furst. New York: Speech and Hearing Institute.

Agnello, J., Wingate, M.E. and Wendell, M. 1974. Voice onset and Voice termination times of child and adult stutterers. *Journal of Acoustic Society of America 56:* 362.

Ainsworth, W.A. 1976. *Mechanisms of Speech Recognition.* Pergamon Press.

Allen, G. 1972. The location of rhythmic stress beats in English: An experimental study. *Language and Speech 15* 72–100.

Allen, G. 1975. Speech rhythm: its relation to performance universals and articulatory timing. *Journal of phonetics 3* 75–86.

Allen, G. and Hawkins, S. 1978. The development of phonological rhythm. In *Syllables and Segments.* Eds. A. Bell and J.B. Hooper. Amsterdam: North Holland.

Barnwell, T.P. 1971. An Algorithm for segment durations in reading machine context. *Technical Report 479.* Cambridge, Mass.: M.I.T. Research Lab. of Electronics.

Boberg, E. 1976. Intensive group therapy program for stutterers. *Human Communication 2:* 21–28.

Boberg, E. 1981. Maintenance of fluency. In *Maintenance of Fluency* New York: Elsevier.

Bolinger, D.L. 1965. Pitch accent and sentence rhythm. In *Forms of English: Accent, Morpheme, order.* Cambridge, Mass.: Harvard University Press.

Borden, G.J. and Harris, K.S. 1980. *Speech Science Primer.* Baltimore: Williams and Wilkins.

Brayton, E.R. and Conture, E.G. 1978. Effects of noise and rhythmic stimulation on the speech of stutterers. *Journal of Speech and Hearing Research 21:* 285–294.

Carlson, R. and Granström, B. 1975. Perception of segmental duration. In *Structure and Process in Speech Perception.* Eds. A. Cohen and S.G. Nooteboom. Heidelberg: Springer–Verlag, 90–104.

Classe, A. 1939. *The Rhythm of English Prose.* Oxford: Blackwell. Colcord, R.D. and Adams, M.R. 1979. Voicing duration and Vocal SPL changes associated with stuttering during singing. *Journal of Speech and Hearing Research 22:* 470–480.

Coleman, C.L. 1974. A study of acoustical and perceptual attributes of isochrony in spoken English. *Ph.D dissertation,* University of Washington.

Cooper, M.H. and Allen, G. 1977. Timing control accuracy in normal speakers and stutterers. *Journal of Speech and Hearing Research 20:* 55–71.

Critcher, C.R. 1979. The recognition of stuttering within the context of fluent speech. *ASHA convention paper:* Atlanta.

Cross, D.E. and Luper, H.L. 1979. Voice reaction time of stuttering and non stuttering children and adults. *Journal of Fluency Disorders 4:* 59–77.

Cross, D.E., Shadden, B.B. and Luper, H.L. 1979. Effects of stimulus ear presentation of the voice reaction times of adult stutterers and non stutterers. *Journal of Fluency Disorders 4:* 45–58.

Dauer, R.M. 1983. Stress– timing and syllable timing reanalyzed. *Journal of Phonetics 11:* 51–62.

Disimoni, F. 1974. Preliminary study of certain timing relationships in the speech of stutterers. *Journal of Acoustic Society of America 56:* 695–696.

Ellis, S.M. and Weismer, G. 1978. More on temporal compensation. *Journal of Acoustic Society of America 63:* S 54.

Fairbanks, G. 1954. A theory of Speech mechanism as a servosystem. *Journal of Speech and Hearing Disorders 19:* 133–139.

Few, L.R. and Lingwall, J.B. 1972. A further analysis of fluency within stuttered speech. *Journal of Speech and Hearing Research 15:* 356–363.

Flege, J.E. and Brown, Jr E.S. 1982. Effects of utterance position on English speech timing. *Phonetica 39:* 337–357.

Fowler, C.A. 1979. "Perceptual Centers" in speech perception and production. *Perception and Psychophysics 25, 5:* 375–388.

Freeman, F.J. and Ushijima, T. 1978. Laryngeal muscle activity during stuttering. *Journal of Speech and Hearing Research 21:* 538–562.

Fromkin, V.A. 1973. *Speech errors as linguistic evidence.* Mouton, The Hague.

Gaitenby, J.H. and Marmelstein, P. 1977. Acoustic correlates of perceived prominence in unknown utterances. *Haskins Laboratories Status Report on Speech Research 49:* 201–216.

Gay, T., Ushijima, T., Hirose, H., and Cooper, F.S. 1974. Effect of speaking rate on labial consonant – vowel articulation. *Journal of Phonetics 2:* 47–63.

Gay, T. 1978. Motor control of speech rate. *Journal of Acoustic Society of America 64:* S(1), 113.

Gay, T. 1981. Mechanisms in the control of speech rate. *Phonetica 38:* 148–158.

Hand, C.R. and Luper, H.L. 1980. Durational characteristics of stutterers' and non stutterers' fluent speech. *ASHA 22:* 709.

Harris, K.S., and Umeda, N. 1974. Effect of speaking mode on temporal factors in speech: Vowel duration. *Journal of Acoustic Society of America 56:* 1016–1018.

Hayden, P.A., Adams, M.R. and Jordahl, N. 1982. The effects of pacing and masking on stutterers' and non stutterers' speech initiation times. *Journal of Fluency Disorders 7:* 9–19.

Healey, C., Mallard, A.R. and Adams, M.R. 1976. Factors contributing to the reduction of stuttering during singing. *Journal of Speech and Hearing Research 19:* 475–480.

Hillman, R.E. and Gilbert, H.H. 1977. Voice onset time for voiceless consonants in the fluent

reading of stutterers and non stutterers. *Journal of Acoustic Society of America 61:* 610–611.

Hotchkiss, J.C. 1973. Perceptual ddifferences in the fluent speech of stutterers and non stutterers. *Unpublished Doctoral dissertation,* Purdue Universuty.

Huggins, A.W.F. 1972. Just– Noticeable differences for segment duration in natural speech. *Journal of Acoustic Society of America 51:* 1270–1278.

Huggins, A.W.F. 1975. On Isochrony and Syntax. In *Auditory analysis and Perception of Speech.* Eds. G. Fant and M. Tatham. London: Academic Press.

Ingham, R.J. and Andrews, G. 1973. Behavior therapy and stuttering: A review. *Journal of Speech and Hearing Disorders 38:* 402–441.

Kelso, J.A.S., Tuller, B. and Harris, K.S. 1981. A "Dynamic pattern" perspective on the control and coordination of movement. *Haskins Laboratories Status Report on Speech Research SR-65:* 157–190.

Kerr, S. and Cooper, E.B. 1976. Phonatory adjustment times in stutterers and non stutterers. *ASHA convention paper:* Houston.

Klatt, D.H. 1973. Interaction between two factors that influence vowel duration. *Journal of Acoustic Society of America 54:* 1102–1104.

Klatt, D.H. 1975. Vowel lengthening is syntactically determined in a connected discourse. *Journal of Phonetics 3:* 161–172.

Klatt, D.H., and Cooper, W.E. 1975. Perception of segment duration in sentence contexts. In *Structure and Process in Speech Perception.* Eds. A. Cohen and S. Nooteboom. Heidelberg: Springer–Verlag.

Klatt, D.H. 1976. Linguistic uses of segmental duration in English: Acoustic and Perceptual evidence. *Journal of Acoustic Society of America 59:* 1208–1221.

Kozhevnikov, N.A. and Chistovich, L.A. 1965. Speech: Articulation and Perception. *JPRS/30543:* Washington D.C.

Lashley, K.S. 1951. The problem of serial order in behaviour. In *Cerebral mechanisms in Behaviour.* Ed. L.A. Jeffress. New York: Wiley.

Lea, W.A. 1974. Prosodic aids to speech recognition:IV. A general strategy for prosodically– guided speech understanding. *Univac Report No. PX10791:* St. Paul, Minn: Sperry Univac, DSD.

Lea, W.A. and Kloker, D.R. 1975. Prosodic aids to speech recognition: VI. Timing cues to linguistic structure and improved computer programs for prosodic analysis. *Univac Report No. PX11239:* St. Paul, Minn: Sperry Univac, DSD.

Lea, W.A. 1975. Prosodic aids to speech recognition: VII. Experiments on detecting and locating phrase boundaries. *Univac Report No. 11534:* St. Paul, Minn: Sperry Univac, DSD.

Lea, W.A. 1976a. Acoustic correlates of stress and juncture. *Univac Report No. PX11693:* St. Paul, Minn: Sperry Univac, DSD.

Lea, W.A. 1976b. The importance of prosodic analysis in speech understanding systems *Univac Report No. PX11694:* St. Paul, Minn: Sperry Univac, DSD.

Lea, W.A. 1976c. Prosodic aids to speech recognition: IX. Acoustic – Prosodic patterns in selected English phrase structures. *Univac Report No. PX11963:* St. Paul, Minn: Sperry Univac, DSD.

Lechner, B.K. 1979. The effects of delayed auditory feedback and masking on the fundamental frequency of stutterers and non stutterers. *Journal of Speech and Hearing Research 22:* 343–353.

Lehiste, I. 1970. *Suprasegmentals.* Cambridge, Mass.: MIT Press.

Lehiste, I. 1972. The timing of utterances and linguistic boundaries. *Journal of Acoustic Society of America 51:* 2018–2024.

Lehiste, I. 1973. Rhythmic units and syntactic units in production and perception. *Journal of Acoustic Society of America 54:* 1228–1234.

Lehiste, I. 1977. Isochrony reconsidered. *Journal of Phonetics 5:* 253–263.

Lehiste, I. Olive, J.P. and Streeter, L.A. 1976. The role of duration in disambiguating syntactically ambiguous sentences. *Journal of Acoustic Society of America 60:* 1199–1202.

Liberman, A.M., Cooper, F.S., Shankweiler,. D.P. and Studdert–Kennedy, M. 1967. Perception of the speech code. *Psychological Review 74:* 431–461.

Lindblom, B. 1964. A note on segment duration in Swedish polysyllables. *QPSR1 Speech Transmission Laboratory:* Stockholm: Royal Institute of Technology.

Lindblom, B. Rapp, K. 1973. Some temporal regularities of spoken Swedish. *Papers from the Institute of Linguistics, publication 21:* University of Stockholm.

MacNeilage, P.F. 1970. Motor control of serial ordering of speech. *Psychological Review 77:* 182–196.

Major, R.C. 1981. Stress–timing in Brazilian Portugese. *Journal of Phonetics 9:* 343–351.

Martin, J.G. 1972. Rhythmic (Hierarchical) versus serial structure in speech and other

behaviours. *Psychological Review 79:* 487–509.

McFarlene, S.C. and Prins, D. 1978. Neural response time of stutterers and non stutterers in selected oral motor tasks. *Journal of Speech and Hearing Research 21:* 768–778.

McFarlene, S.C. and Shipley, K.C. 1981. Latency and Vocalization onset for stutterers and non stutterers under conditions of auditory and visual cueing. *Journal of Speech and Hearing Disorder:* 307–312.

Metz, D.E., Conture, E.G. and Caruso, A. 1979. Voice onset time, frication and aspiration during stutterers' fluent speech. *Journal of Speech and Hearing Research 22:* 649–656.

Miller, J.L. and Liberman, A.M. 1979. Some effects of later occuring information on the perception of stop consonant and semivowel. *Perception and Psychophysics 25:* 457–465.

Morton, J., Marcus, S.M. and Frankish, C.R. 1976. Perceptual centers (P–centers). *Psychological Review 83:* 405– 408.

Nakatani, L.H., O'Connor, K.D. and Aston, C.H. 1981. Prosodic aspects of American English Speech Rhythm 38: 84–106.

Nooteboom, S.G. 1973. The perceptual reality of some prosodic durations. *Journal of Phonetics 1:* 25–45.

Nooteboom, S.G. 1975. On the internal auditory representation of syllable nucleus duration. In *Auditory analysis and Perception of Speech.* Eds. G. Fant and M. Tatham. London: Academic Press.

Nooteboom, S.G. and Cohen, A. 1975. Anticipation in spech production and its implications for perception. In *Structure and Process in Speech Perception.* Heidelberg: Springer–Verlag, 124–142.

Novak, A. 1978. The influence of delayed auditory feedback on stutterers. *Folia Phoniatrica 10:* 87–99.

O'Connor, J.D. The perception of time intervals. 1965. *Phonetics Laboratory Progress Report 2:* University College, London, 11–15.

O'Connor, J.D. 1968. The duration of foot in relation to number of component segments. *Phonetics Laboratory Progress Report 3:* University College, London, 1–6.

Ohala, J.J. 1975. The temporal regulation of speech. In *Auditory analysis and Perception of Speech.* Eds. G. Fant and M. Tatham. London: Academic Press, 431–453.

Oller, D.K. 1973. The effect of position in utterance on speech segment duration in English.

Journal of Acoustic Society of America 54: 1235–1247.

Perkins, W.H. 1979. From Psycho–analysis to Discoordination. In *Controversies about stuttering therapy.* Ed. H.H. Gregory. Baltimore: University Park Press.

Perkins, W.H., Bell, J., Johnson, L. and Stocks, J. 1979. Phone rate and the effective planning time hypothesis of stuttering. *Journal of Speech and Hearing Research 22:* 747–755.

Pike, K.L. 1945. *The Intonation of American English.* Ann Arbor, Mich.: Univ. of Michigan Press.

Port, R. 1981. Linguistic timing factors in combination. *Journal of Acoustic Society of America 69:* 262–274.

Port, R. Al–Ani, S. and Maeda, S. 1980. Temporal compensation and universal phonetics. *Phonetica 37:* 235–252.

Potapova, R. K. 1975. Auditory estimate of syllable and vowel durations in sentences. In *Auditory analysis and Perseption of Speech.* Eds. G. Fant and M. Tatham. London: Academic Press, 465–475.

Prosek, R.A., Montgomery, A.A., Walden, V.E. and Schwartz, D.M. 1979. Reaction time measures of stutterers and non stutterers. *Journal of Fluency Disorders 4:* 269–279.

Prosek, R.A. and Runyan, C.M. 1982. Temporal characteristics related to the discrimination of stutterers' and non stutterers' speech samples. *Journal of Speech and Hearing Research 25:* 29–33.

Rakerd, B., Verbrugge, R.V. and Shankweiler, D.P. 1980. Speaking rate, syllable stress and vowel identity. *Haskins Laboratories Status Report on Speech Research SR-62:* 149–160.

Ramig, P.R. and Adams, M.R. 1981. Vocal changes in stutterers and non stutterers during high– and low– pitched speech. *Journal of Fluency Disorders 6:* 15–33.

Rapp. K. 1971. A study of syllable timing. *STL- QPSR 1:* 14–19.

Reich, A., Till, J. and Goldsmith, H. 1981. Laryngeal and manual reaction times of stuttering and non stuttering adults. *Journal of Speech and Hearing Research 24:* 192–196.

Runyan, C.M., and Adams, M.R. 1978. Perceptual study of the speech of "sucessfully therapeutized" stutterers. *Journal of Fluency Disorders 3:* 25–39.

Runyan, C.M. and Adams, M.R. 1979. Unsophisticatedd judges' perceptual evaluation of the speech of "sucessfully treated" stutterers. *Journal of Fluency Disorders 4:*

29–38.

Ryan, B. 1974. *Programmed therapy for stuttering children and adults*. Springfield, Ill.: Charles C. Thomas.

Ryan, B. 1979. Stuttering therapy in a framework of operant conditioning and programmed learning. In *Controversies about Stuttering Therapy*. Ed. H.H. Gregory. Baltimore: University Park Press.

Shapiro, A. 1980. An electromyographic analysis of the fluent and dysfluent utterances of several types of stutterers. *Journal of Fluency Disorders 5:* 203–232.

Shapiro, C.W. 1970. Phrasal stress patterns of the fluent speech of stutterers and nonstutterers. *M.A. thesis, State University of New York,* Buffalo.

Shen, Y. and Peterson, G.G. 1962. Isochronism in English. *Studies in Linguistics, Occasional Papers 9:* University of Buffallo, 1–36.

Starkweather, C.W., Hirschman, P. and Tannenbaum, R. 1976. Latency and vocalization onset: Stutterers Vs. non stutterers. *Journal of Speech and Hearing Research 19:* 481–492.

Starkweather, C.W. and Myers, N. 1979. Duration of subsegments within intervocalic interval in stutterers and non stutterers. *Journal of Fluency Disorders 4:* 205–214.

Stevenson, D. and Stephens, R. 1978. *The Alligator reference manual.* Unpublished manauscript, Univ. of Alberta.

Tuller, B. and Fowler, C.A. 1980. Some articulatory correlates of perceptual isochrony. *Haskins Laboratory Status Report on Speech Research SR-62:* 87–100.

Tuller, B. and Fowler, C.A. 1981. The contribution of amplitude to the perception of isochrony. *Haskins Laboratory Status Report on Speech Research SR-65:* 245–250.

Tuller, B., Harris, K.S. and Kelso, J.A.S. 1980. Temporal models of interarticulator programming. *Journal of Acoustic Society of America 67(A):* S64.

Tuller, B., Harris, K.S. and Kelso, J.A.S. 1981. Articulatory motor events as a function of speaking rate and stress. *Haskins Laboratories Status Report on Speech Research SR-65:* 33–62.

Tuller, B., Kelso, J.A.S. and Harris, K.S. 1981. Phase relationships among articulator muscles as a function of speaking rate and stress. *Haskins Laboratories Status Report on Speech Research SR-65:* 63–89.

Uldall, E.T. 1971. Isochronous stresses in R. P. In *Form and Substance: Phonetic and*

Linguistic papers presented to Eli Fisher-Jorgensen. Eds. L. L. Hammerich, R. Jakobson, and Z. Eberhard. Copenhagen: Akademisk Forlag, 205–210.

Uldall, E.T. 1972. Relative durations of syllables in twosyllable rhythmic feet in R.P. in connected speech. *Work in Progress 5:* Edinburg University: Dept. of Linguistics, 110–111.

Umeda, N. 1972. Vowel duration in polysyllabic words in American English. *Journal of Acoustic Society of America 52:* 133(A).

VanRiper, C. 1982. *The Nature of Stuttering.* Englewood cliffs, New Jersey: Prentice-Hall.

Venkatagiri, H.S. 1981. Reaction time for voiced and whispered /a/ in stutterers and non stutterers. *Journal of Fluency Disorders 6:* 265–271.

Wendahl, R.W. and Cole, J. 1961. Identification of stuttering during relatively fluent speech. *Journal of Speech and Hearing Research 4:* 281–286.

Williams, D.C. 1957. A point of view about stuttering. *Journal of Speech and Hearing Disorders 22:* 390–397.

Wingate, M.E. 1969. Sound and pattern in artificial fluency. *Journal of Speech and Hearing Research 12:* 677–686.

Wingate, M.E. 1970. Effect on stuttering of changes in audition. *Journal of Speech and Hearing Research 13:* 861–873.

Wingate, M.E. 1976. *Stuttering: Theory and Treatment.* New York: Irvington-Wiley.

Wingate, M.E. 1979. The first three words. *Journal of Speech and Hearing Research 22:* 604–612.

Wingate, M.E. 1981. Sound and pattern in artificial fluency: Spectrographic evidence. *Journal of Fluency Disorders 6:* 95–118.

Wingate, M.E. 1982. Early position and stuttering occurrence. *Journal of Fluency Disorders 1:* 243–258.

Zimmerman, G.N. 1980. Articulatory behaviors associated with stuttering: A cinefluorographic analysis. *Journal of Speech and Hearing Research 23:* 108–121.

APPENDIX I - STIMULUS MATERIAL

NOTE: Measurements were made on units underlined with stress markings.

NARRATIVE PASSAGE

Few prehistoric animals could have captured the imagination so completely as have the flying reptiles known as the pterosaurs. Extinct for the sixty four million years that have passed since the end of the mesozoic era, these dragons of the air have nonetheless figured prominently in man's view of the distant past ever since Arthur Conan Doyle made them part of the "Lost World". For almost two centuries paleontologists have been puzzling over the fossil remains of the pterosaurs, and surely others have wondered how the pterosaurs solved the problems of powered flight. Hang-gliding enthusiasts might well be curious because the larger pterosaurs weighed as much as a hang-glider pilot. In 1830 Johann Wagler linked the pterosaurs to the extinct marine reptiles.

Until recently it was thought that pterosaurs with wingspans as great as eight meters represented the maximum size for flying animals. Nine years ago, however, Douglas A. Lawson discovered bones that were quite large. The radius, the forearm bone, measured almost three quarters of a meter long. No additional remains of this animal, named after the Aztec god who took the form of a feathered serpent, have come to light since then.

EXTRACT FROM RADIO PLAY

John: He should have posted it.

Head: How much do you know about it, man?

John: Wittering. I simply don't believe it.

Inspector: Then it's news to you , sir?

John: News? Of course it is.

Inspector: He seems to infer that you were present while he was being bullied.

John: Does he?

Inspector: They were on at me worse than ever, even with the new master.

Head: And where were you?

John: Was I where?

Head: With them in the garage?

John: Oh no. I wasn't with them. I stood far away watching.

Inspector: You are quite sure of that, sir.

Head: Mind you, inspector, it's a highly hysterical letter.

Inspector: These sort of things generally are.

Head: All that rubbish about killing Mr.Pelham.

Inspector: Yes, sir, I'm sure a word or two with the boys will clear that up.

Head: It's so fantastic I should hardly have thought it worth troubling about.

Inspector: I'd like to speak to them though, sir.

Head: Yes, of course. I'll take you along to them now.

Inspector: I'd rather see them individually, if you don't mind, sir.

Head: One by one? They could be dangerous!

Inspector: Please sir.

Head: Are'nt you perhaps making rather much of this?

Inspector: I don't think so, sir. I can easily see them down at the station.

Head: Oh no, no. Much better to see them here.

Inspector: Do you know of other witnesses?

John: Yes, Christopher and Bob. They told me about other happenings as well.

RHYTHMIC UNITS IN SPECIAL SENTENCES (RUSS)

The credit proved to be a mixed blessing.

The creditor approved the contract.

However, Credit disapproved of the loan.

The credit approved was insufficient.

The creditor disapproved of our plans.

He credibly proved his point.

The management creditably approved the plan.

The point was credibly disproved by John.

The management creditably disapproved of the takeover.

This creditor disproved the point.

The creditor proved to be stubborn.

He creditably proved his point.

The point was creditably proved by John.

NOTE: Measurements were made on units underlined with stress markings.

APPENDIX II - PROGRAM FOR AUTOMATIC SEGMENTATION

SAMPLING OF SPEECH

```
CLEAR ALL
LABEL 1
DATA Y
DATA T
DATA SEG*8
READ *TTY &SEG
SET NTH=32
SET FREQ=8
SET SDIAL=3
SET SCROLL=ON
LABEL 0
CONTROL TR:PLAY
IF #SS:5 EQ 1 GOTO 0
SAMPLE
CONTROL TR:STOP

P
ED
LABEL 2
LOCK
WAIT 3SEC
IF #SS:1 EQ 1 PCURSE
IF #SS:2 EQ 1 PLAY
IF #SS:0 EQ 1 GOTO 2
EX &SEG
RETURN

QUE &SEG
MEAS DUR &Y &T
PRINT &Y &T
SET FMODE=ON
CALP
APH ON
SET FREQ=1
WAIT 5SEC
PLAY

WAIT 1SEC
DWA &SEG
GOTO 1 END
```

SIGNAL EDITING

```
PR SENSE SWITCH 1 PLAYS WHOLE SIGNAL
```

```
        SENSE SWITCH 0 PLAYS BETWEEN CURSORS
PR BEFORE YOU FINISH LAST SEGMENT, PRESS SENSE SWITCH 3


DATA Y
DATA T
DATA SEG*8
LABEL 0
PR GIVE ME SEGMENT NAME
READ *TTY &SEG
SET NTH =64



C       SIGNAL EXTRACTION AND DURATION MEASUREMENTS
EDITOR
LABEL 1
LOCK
WAIT 3SEC
IF #SS:0 EQ 1 PCURSE
IF #SS:1 EQ 1 PLAY
IF #SS:5 EQ 0 GOTO 1
EX &SEG
RETURN


QUE &SEG
MEASURE DUR &Y &T
PRINT &Y &T
SINK NUMBER *OUT
WRITE *OUT &SEG &Y &T
PLAY


SET FMODE=ON
SET TP=8
CALP
PLOT 0 950 125
DWA &SEG
QUE SAM
IF #SS:3 EQ 1 LINK SIG
GOTO 0
END
```

<u>RETREIVAL OF SIGNAL FROM DISK</u>

```
CLEAR ALL
SET VI=600
DATA X 0
DATA Y 16
$SYS GET 5 0 0 0


SAMPLE
PR GIVE ME DISK STARTING BLOCK NUMBER
READ *TTY &X
LABEL 0
$SYS READ &X 20 0 &Y
```

```
ADD &X 16


PRINT &X &Y
ADD &Y 8
IF &Y LE 56 GOTO 0
SCALE 1000 511
PLAY
PR NOW YOU HAVE SIGNAL, PRESS SENSE SWITCH 3
LABEL 2
IF #SS:3 EQ 1 LINK G1
GOTO 2
END
```

APPENDIX III - BMDP PROGRAMS FOR ANOVA

ANOVA PROGRAM FOR ISI

```
/PROBLEM      TITLE IS 'FOOT MEASUREMENTS'.
/INPUT        VARIABLES ARE 16. FORMAT IS FREE.
              MTSFILE IS GDAT3.
/VARIABLE     NAMES ARE F1T1,F1T2,F1T3,F1T4,
              F2T1,F2T2,F2T3,F2T4,
              F3T1,F3T2,F3T3,F3T4,
              F4T1,F4T2,F4T3,F4T4.
/DESIGN       LEVELS ARE 2,9,4,4.
              NAMES ARE  G,S,F,T.
              FIXED ARE G,F.
              RANDOM IS S,T.
              MODEL IS 'G,S(G),F,T(GSF)'.
              PRINT='GSTF'.
/END
```

ANOVA PROGRAM FOR 1USV AND TUSV

```
/PROBLEM        TITLE IS 'TIME MEASURE ALL'.
/INPUT          VARIABLES ARE 32. FORMAT IS FREE.
                MTSFILE IS 'GDAT3A'.
/VARIABLE       NAMES ARE
                F2T1US,F2T1UST,
                F2T2US,F2T2UST,
                F2T3US,F2T3UST,
                F2T4US,F2T4UST,
                F3T1US,F3T1UST,
                F3T2US,F3T2UST,
                F3T3US,F3T3UST,
                F3T4US,F3T4UST,
                F4T1US,F4T1UST,
                F4T2US,F4T2UST,
                F4T3US,F4T3UST,
                F4T4US,F4T4UST,
                F5T1US,F5T1UST,
                F5T2US,F5T2UST,
                F5T3US,F5T3UST,
                F5T4US,F5T4UST.
/DESIGN         LEVELS ARE 2,9,4,4.
                NAMES  ARE G,S,F,T.
                FIXED  ARE G,F.
                RANDOM IS  S,T.
                MODEL  IS  'G,S(G),F,T(GSF)'.
                PRINT  = 'GSTF'.
                NDEP   =  2.
/END
```

ANOVA PROGRAM FOR SV AND IVI

```
/PROBLEM        TITLE IS 'TIME MEASURE ON TWO'.
/INPUT          VARIABLES ARE 40. FORMAT IS FREE.
                MTSFILE IS 'GDAT3B'.
/VARIABLE       NAMES ARE
                F1T1SV,F1T1IV,
                F1T2SV,F1T2IV,
                F1T3SV,F1T3IV,
                F1T4SV,F1T4IV,
                F2T1SV,F2T1IV,
                F2T2SV,F2T2IV,
                F2T3SV,F2T3IV,
                F2T4SV,F2T4IV,
                F3T1SV,F3T1IV,
                F3T2SV,F3T2IV,
                F3T3SV,F3T3IV,
                F3T4SV,F3T4IV,
                F4T1SV,F4T1IV,
                F4T2SV,F4T2IV,
                F4T3SV,F4T3IV,
                F4T4SV,F4T4IV,
                F5T1SV,F5T1IV,
                F5T2SV,F5T2IV,
                F5T3SV,F5T3IV,
                F5T4SV,F5T4IV,
/DESIGN         LEVELS ARE 2,9,5,4.
                NAMES  ARE G,S,F,T.
                FIXED  ARE G,F.
                RANDOM IS  S,T.
                MODEL  IS  'G,S(G),F,T(GSF)'.
                PRINT  = 'GSTF'.
                NDEP   =  2.
/END
```

APPENDIX IV - CELL AND MARGINAL MEANS

MEANS FOR INTERSTRESS INTERVALS

GRAND MEAN 451.59722

CELL AND MARGINAL MEANS

G =	1	2
	508.86806	394.32639

F =	1	2	3	4
	258.76389	410.33333	489.30556	647.98611

	S =	1	2	3	4	5
G =	1	421.250	540.8125	547.3125	486.75	545.9375
	2	408.125	390.0620	390.4375	348.50	355.5625

	S=	6	7	8	9
G =	1	643.56250	559.25000	434.18750	400.75000
	2	455.06250	389.00000	434.43750	377.75000

	F =	1	2	3	4
G =	1	278.44444	455.11111	553.16667	748.75000
	2	239.08333	365.55556	425.44444	547.22222

G = 1

	F =	1	2	3	4
S =	1	270.00000	402.00000	396.00000	617.00000
	2	281.00000	497.00000	641.25000	744.00000
	3	213.00000	489.00000	541.25000	946.00000
	4	324.00000	397.00000	544.00000	682.00000
	5	252.00000	521.00000	522.75000	888.00000
	6	363.00000	509.00000	745.25000	957.00000
	7	333.00000	530.00000	629.25000	744.75000
	8	238.00000	381.00000	486.75000	631.00000
	9	232.00000	370.00000	472.00000	529.00000

G = 2

	F =	1	2	3	4
S =	1	227.00000	372.00000	498.50000	535.00000
	2	238.00000	355.00000	405.25000	562.00000
	3	244.00000	377.00000	390.75000	550.00000
	4	222.00000	315.00000	376.00000	481.00000
	5	233.00000	343.00000	348.00000	498.25000
	6	281.00000	428.00000	466.25000	645.00000
	7	220.75000	327.00000	472.25000	536.00000
	8	252.00000	421.00000	478.75000	586.00000
	9	234.00000	352.00000	393.25000	531.75000

G = 1 S = 1

T =	1	2	3	4
F = 1	288.00000	288.00000	320.00000	184.00000
2	352.00000	576.00000	340.00000	340.00000
3	396.00000	288.00000	508.00000	392.00000
4	756.00000	544.00000	536.00000	632.00000

G = 1 S = 2

T =	1	2	3	4
F = 1	288.00000	244.00000	316.00000	276.00000
2	568.00000	504.00000	416.00000	500.00000
3	641.00000	800.00000	660.00000	464.00000
4	952.00000	680.00000	708.00000	636.00000

G = 1 S = 3

T =	1	2	3	4
F = 1	188.00000	224.00000	292.00000	148.00000
2	732.00000	452.00000	388.00000	384.00000
3	541.00000	432.00000	712.00000	480.00000
4	1128.00000	1420.00000	600.00000	636.00000

G = 1 S = 4

T =	1	2	3	4
F = 1	328.00000	344.00000	356.00000	268.00000
2	460.00000	304.00000	372.00000	452.00000
3	544.00000	544.00000	532.00000	556.00000
4	792.00000	724.00000	660.00000	552.00000

G = 1 S = 5

T =	1	2	3	4
F = 1	220.00000	272.00000	316.00000	200.00000
2	564.00000	660.00000	416.00000	444.00000
3	523.00000	456.00000	680.00000	432.00000
4	1072.00000	932.00000	924.00000	624.00000

G = 1 S = 6

T =	1	2	3	4
F = 1	420.00000	400.00000	380.00000	252.00000
2	544.00000	484.00000	492.00000	516.00000
3	745.00000	580.00000	824.00000	832.00000
4	1048.00000	692.00000	764.00000	1324.00000

G = 1 S = 7

T =	1	2	3	4
F = 1	356.00000	416.00000	304.00000	256.00000
2	704.00000	448.00000	464.00000	504.00000
3	629.00000	564.00000	716.00000	608.00000
4	868.00000	736.00000	655.00000	720.00000

G = 1 S = 8

T =	1	2	3	4
F = 1	224.00000	268.00000	268.00000	192.00000
2	444.00000	392.00000	260.00000	428.00000
3	487.00000	524.00000	548.00000	388.00000
4	684.00000	584.00000	532.00000	724.00000

```
      G =  1    S =  9
      T =      1            2            3            4
F =   1   236.00000    292.00000    208.00000    192.00000
      2   368.00000    324.00000    400.00000    388.00000
      3   472.00000    484.00000    552.00000    380.00000
      4   616.00000    612.00000    472.00000    416.00000

      G =  2    S =  1
      T =      1            2            3            4
F =   1   224.00000    224.00000    268.00000    192.00000
      2   368.00000    344.00000    328.00000    448.00000
      3   498.00000    568.00000    512.00000    416.00000
      4   524.00000    624.00000    544.00000    448.00000

      G =  2    S =  2
      T =      1            2            3            4
F =   1   200.00000    248.00000    252.00000    252.00000
      2   340.00000    348.00000    396.00000    336.00000
      3   405.00000    432.00000    448.00000    336.00000
      4   596.00000    616.00000    580.00000    456.00000

      G =  2    S =  3
      T =      1            2            3            4
F =   1   196.00000    276.00000    288.00000    216.00000
      2   424.00000    344.00000    312.00000    428.00000
      3   391.00000    348.00000    436.00000    388.00000
      4   576.00000    616.00000    588.00000    420.00000

      G =  2    S =  4
      T =      1            2            3            4
F =   1   196.00000    232.00000    240.00000    220.00000
      2   320.00000    216.00000    324.00000    400.00000
      3   376.00000    380.00000    388.00000    360.00000
      4   544.00000    552.00000    456.00000    372.00000

      G =  2    S =  5
      T =      1            2            3            4
F =   1   208.00000    224.00000    284.00000    216.00000
      2   328.00000    356.00000    300.00000    388.00000
      3   348.00000    344.00000    384.00000    316.00000
      4   593.00000    524.00000    492.00000    384.00000

      G =  2    S =  6
      T =      1            2            3            4
F =   1   260.00000    340.00000    304.00000    220.00000
      2   404.00000    528.00000    348.00000    432.00000
      3   466.00000    396.00000    480.00000    523.00000
      4   680.00000    652.00000    680.00000    568.00000

      G =  2    S =  7
      T =      1            2            3            4
F =   1   187.00000    276.00000    232.00000    188.00000
      2   324.00000    296.00000    328.00000    360.00000
```

		1	2	3	4
	3	472.00000	568.00000	464.00000	385.00000
	4	576.00000	544.00000	516.00000	508.00000

G = 2 S = 8

	T =	1	2	3	4
F =	1	216.00000	300.00000	308.00000	184.00000
	2	432.00000	396.00000	436.00000	420.00000
	3	479.00000	420.00000	600.00000	416.00000
	4	652.00000	596.00000	528.00000	568.00000

G = 2 S = 9

	T =	1	2	3	4
F =	1	204.00000	252.00000	248.00000	232.00000
	2	388.00000	292.00000	344.00000	384.00000
	3	393.00000	316.00000	496.00000	368.00000
	4	568.00000	531.00000	528.00000	500.00000

MEANS FOR FIRST UNSTRESSED VOWELS

GRAND MEAN 58.51389

CELL AND MARGINAL MEANS

G =	1	2
	68.24306	48.78472

F =	1	2	3	4
	55.77778	69.33333	60.94444	48.00000

	S =	1	2	3	4	5
G =	1	41.6875	75.4375	83.2500	61.5625	80.9375
	2	40.9375	43.0625	48.5625	43.5625	54.7500

	S =	6	7	8	9
G =	1	59.50000	49.43750	54.75000	44.50000
	2	77.25000	69.25000	61.25000	63.56250

	F =	1	2	3	4
G =	1	64.00000	78.97222	72.22222	57.77778
	2	47.55556	59.69444	49.66667	38.22222

G = 1

	F =	1	2	3	4
S =	1	42.00000	42.75000	50.00000	32.00000
	2	83.00000	90.75000	72.00000	56.00000
	3	75.00000	72.00000	86.00000	100.00000
	4	58.00000	81.25000	55.00000	52.00000
	5	69.00000	90.75000	116.00000	48.00000

6	69.00000	100.00000	68.00000	72.00000
7	61.00000	76.00000	76.00000	64.00000
8	57.00000	68.00000	64.00000	56.00000
9	62.00000	89.25000	63.00000	40.00000

G = 2

	F =	1	2	3	4
S =	1	39.00000	54.75000	46.00000	24.00000
	2	52.00000	41.25000	55.00000	24.00000
	3	35.00000	65.25000	50.00000	44.00000
	4	42.00000	45.25000	47.00000	40.00000
	5	47.00000	76.00000	48.00000	48.00000
	6	72.00000	76.00000	50.00000	40.00000
	7	40.00000	66.75000	47.00000	44.00000
	8	57.00000	60.00000	54.00000	48.00000
	9	44.00000	52.00000	50.00000	32.00000

G = 1 S = 1

	T =	1	2	3	4
F =	1	36.00000	40.00000	36.00000	56.00000
	2	43.00000	32.00000	44.00000	52.00000
	3	36.00000	60.00000	32.00000	72.00000
	4	32.00000	32.00000	32.00000	32.00000

G = 1 S = 2

	T =	1	2	3	4
F =	1	68.00000	100.00000	112.00000	52.00000
	2	91.00000	116.00000	88.00000	68.00000
	3	48.00000	92.00000	36.00000	112.00000
	4	56.00000	56.00000	56.00000	56.00000

G = 1 S = 3

	T =	1	2	3	4
F =	1	64.00000	140.00000	60.00000	36.00000
	2	72.00000	84.00000	64.00000	68.00000
	3	72.00000	80.00000	64.00000	128.00000
	4	100.00000	100.00000	100.00000	100.00000

G = 1 S = 4

	T =	1	2	3	4
F =	1	56.00000	80.00000	64.00000	32.00000
	2	81.00000	104.00000	60.00000	80.00000
	3	40.00000	68.00000	32.00000	80.00000
	4	52.00000	52.00000	52.00000	52.00000

G = 1 S = 5

	T =	1	2	3	4
F =	1	76.00000	100.00000	60.00000	40.00000
	2	91.00000	104.00000	96.00000	72.00000
	3	80.00000	204.00000	36.00000	144.00000
	4	48.00000	48.00000	48.00000	48.00000

G = 1 S = 6

	T =	1	2	3	4

```
F =  1    52.00000   128.00000    56.00000    40.00000
     2   100.00000    80.00000   152.00000    68.00000
     3    40.00000    88.00000    36.00000   108.00000
     4    72.00000    72.00000    72.00000    72.00000

    G =  1    S =  7
    T =        1           2           3           4
F =  1    76.00000   104.00000    36.00000    28.00000
     2    76.00000    56.00000    84.00000    88.00000
     3    52.00000    88.00000    36.00000   128.00000
     4    64.00000    64.00000    64.00000    64.00000

    G =  1    S =  8
    T =        1           2           3           4
F =  1    52.00000   112.00000    36.00000    28.00000
     2    68.00000    72.00000    72.00000    60.00000
     3    40.00000    60.00000    36.00000   120.00000
     4    56.00000    56.00000    56.00000    56.00000

    G =  1    S =  9
    T =        1           2           3           4
F =  1    44.00000   108.00000    52.00000    44.00000
     2    89.00000   104.00000   112.00000    52.00000
     3    64.00000    76.00000    28.00000    84.00000
     4    40.00000    40.00000    40.00000    40.00000

    G =  2    S =  1
    T =        1           2           3           4
F =  1    24.00000    68.00000    32.00000    32.00000
     2    55.00000    60.00000    48.00000    56.00000
     3    40.00000    40.00000    32.00000    72.00000
     4    24.00000    24.00000    24.00000    24.00000

    G =  2    S =  2
    T =        1           2           3           4
F =  1    40.00000    68.00000    48.00000    52.00000
     2    41.00000    36.00000    48.00000    40.00000
     3    52.00000    60.00000    28.00000    80.00000
     4    24.00000    24.00000    24.00000    24.00000

    G =  2    S =  3
    T =        1           2           3           4
F =  1    36.00000    56.00000    24.00000    24.00000
     2    65.00000    52.00000    76.00000    68.00000
     3    36.00000    64.00000    32.00000    68.00000
     4    44.00000    44.00000    44.00000    44.00000

    G =  2    S =  4
    T =        1           2           3           4
F =  1    40.00000    72.00000    28.00000    28.00000
     2    45.00000    48.00000    52.00000    36.00000
     3    44.00000    68.00000    28.00000    48.00000
     4    40.00000    40.00000    40.00000    40.00000
```

G = 2 S = 5

	T = 1	2	3	4
F = 1	56.00000	64.00000	28.00000	40.00000
2	76.00000	44.00000	136.00000	48.00000
3	56.00000	60.00000	24.00000	52.00000
4	48.00000	48.00000	48.00000	48.00000

G = 2 S = 6

	T = 1	2	3	4
F = 1	52.00000	136.00000	52.00000	48.00000
2	76.00000	56.00000	76.00000	96.00000
3	60.00000	80.00000	36.00000	24.00000
4	40.00000	40.00000	40.00000	40.00000

G = 2 S = 7

	T = 1	2	3	4
F = 1	36.00000	56.00000	40.00000	28.00000
2	67.00000	76.00000	76.00000	48.00000
3	36.00000	64.00000	28.00000	60.00000
4	44.00000	44.00000	44.00000	44.00000

G = 2 S = 8

	T = 1	2	3	4
F = 1	68.00000	68.00000	28.00000	64.00000
2	60.00000	52.00000	68.00000	60.00000
3	40.00000	64.00000	24.00000	88.00000
4	48.00000	48.00000	48.00000	48.00000

G = 2 S = 9

	T = 1	2	3	4
F = 1	32.00000	88.00000	24.00000	32.00000
2	52.00000	40.00000	64.00000	52.00000
3	44.00000	72.00000	16.00000	68.00000
4	32.00000	32.00000	32.00000	32.00000

MEANS FOR TOTAL UNSTRESSED VOWELS

GRAND MEAN 174.40278

CELL AND MARGINAL MEANS

G =	1	2
	199.19444	149.61111

F =	1	2	3	4
	55.77778	124.94444	213.33333	303.55556

S =	1	2	3	4	5

G =	1	131.3125	209.7500	210.5625	196.875	231.0000
	2	131.2500	148.0625	143.4375	139.750	152.1875

	S =	6	7	8	9
G =	1	207.87500	179.68750	215.43750	210.25000
	2	193.18750	151.50000	156.56250	130.56250

	F =	1	2	3	4
G =	1	64.00000	141.88889	237.55556	353.33333
	2	47.55556	108.00000	189.11111	253.77778

G = 1

	F =	1	2	3	4
S =	1	42.00000	89.25000	182.00000	212.00000
	2	83.00000	156.00000	244.00000	356.00000
	3	75.00000	133.25000	222.00000	412.00000
	4	58.00000	138.50000	227.00000	364.00000
	5	69.00000	168.00000	339.00000	348.00000
	6	69.00000	190.50000	236.00000	336.00000
	7	61.00000	114.75000	243.00000	300.00000
	8	57.00000	134.75000	210.00000	460.00000
	9	62.00000	152.00000	235.00000	392.00000

G = 2

	F =	1	2	3	4
S =	1	39.00000	104.00000	170.00000	212.00000
	2	52.00000	89.25000	199.00000	252.00000
	3	35.00000	110.75000	196.00000	232.00000
	4	42.00000	108.00000	173.00000	236.00000
	5	47.00000	118.75000	187.00000	256.00000
	6	72.00000	146.75000	222.00000	332.00000
	7	40.00000	116.00000	174.00000	276.00000
	8	57.00000	97.25000	208.00000	264.00000
	9	44.00000	81.25000	173.00000	224.00000

G = 1 S = 1

	T =	1	2	3	4
F =	1	36.00000	40.00000	36.00000	56.00000
	2	89.00000	72.00000	124.00000	72.00000
	3	204.00000	196.00000	172.00000	156.00000
	4	212.00000	212.00000	212.00000	212.00000

G = 1 S = 2

	T =	1	2	3	4
F =	1	68.00000	100.00000	112.00000	52.00000
	2	156.00000	208.00000	148.00000	112.00000
	3	220.00000	268.00000	248.00000	240.00000
	4	356.00000	356.00000	356.00000	356.00000

G = 1 S = 3

	T =	1	2	3	4
F =	1	64.00000	140.00000	60.00000	36.00000
	2	133.00000	148.00000	124.00000	128.00000
	3	256.00000	248.00000	168.00000	216.00000

	4	412.00000	412.00000	412.00000	412.00000

G = 1 S = 4

	T =	1	2	3	4
F =	1	56.00000	80.00000	64.00000	32.00000
	2	114.00000	208.00000	112.00000	120.00000
	3	276.00000	216.00000	168.00000	248.00000
	4	364.00000	364.00000	364.00000	364.00000

G = 1 S = 5

	T =	1	2	3	4
F =	1	76.00000	100.00000	60.00000	40.00000
	2	168.00000	160.00000	188.00000	156.00000
	3	344.00000	444.00000	300.00000	268.00000
	4	348.00000	348.00000	348.00000	348.00000

G = 1 S = 6

	T =	1	2	3	4
F =	1	52.00000	128.00000	56.00000	40.00000
	2	190.00000	144.00000	304.00000	124.00000
	3	260.00000	232.00000	212.00000	240.00000
	4	336.00000	336.00000	336.00000	336.00000

G = 1 S = 7

	T =	1	2	3	4
F =	1	76.00000	104.00000	36.00000	28.00000
	2	115.00000	96.00000	128.00000	120.00000
	3	236.00000	248.00000	200.00000	288.00000
	4	300.00000	300.00000	300.00000	300.00000

G = 1 S = 8

	T =	1	2	3	4
F =	1	52.00000	112.00000	36.00000	28.00000
	2	135.00000	136.00000	176.00000	92.00000
	3	248.00000	184.00000	196.00000	212.00000
	4	460.00000	460.00000	460.00000	460.00000

G = 1 S = 9

	T =	1	2	3	4
F =	1	44.00000	108.00000	52.00000	44.00000
	2	152.00000	200.00000	176.00000	80.00000
	3	272.00000	240.00000	212.00000	216.00000
	4	392.00000	392.00000	392.00000	392.00000

G = 2 S = 1

	T =	1	2	3	4
F =	1	24.00000	68.00000	32.00000	32.00000
	2	104.00000	112.00000	124.00000	76.00000
	3	116.00000	240.00000	152.00000	172.00000
	4	212.00000	212.00000	212.00000	212.00000

G = 2 S = 2

	T =	1	2	3	4
F =	1	40.00000	68.00000	48.00000	52.00000

2	89.00000	124.00000	80.00000	64.00000
3	188.00000	216.00000	212.00000	180.00000
4	252.00000	252.00000	252.00000	252.00000

G = 2 S = 3

T =	1	2	3	4
F = 1	36.00000	56.00000	24.00000	24.00000
2	111.00000	108.00000	128.00000	96.00000
3	192.00000	244.00000	200.00000	148.00000
4	232.00000	232.00000	232.00000	232.00000

G = 2 S = 4

T =	1	2	3	4
F = 1	40.00000	72.00000	28.00000	28.00000
2	108.00000	128.00000	116.00000	80.00000
3	208.00000	232.00000	124.00000	128.00000
4	236.00000	236.00000	236.00000	236.00000

G = 2 S = 5

T =	1	2	3	4
F = 1	56.00000	64.00000	28.00000	40.00000
2	119.00000	108.00000	176.00000	72.00000
3	176.00000	236.00000	176.00000	160.00000
4	256.00000	256.00000	256.00000	256.00000

G = 2 S = 6

T =	1	2	3	4
F = 1	52.00000	136.00000	52.00000	48.00000
2	147.00000	132.00000	148.00000	160.00000
3	264.00000	244.00000	224.00000	156.00000
4	332.00000	332.00000	332.00000	332.00000

G = 2 S = 7

T =	1	2	3	4
F = 1	36.00000	56.00000	40.00000	28.00000
2	116.00000	120.00000	160.00000	68.00000
3	184.00000	196.00000	148.00000	168.00000
4	276.00000	276.00000	276.00000	276.00000

G = 2 S = 8

T =	1	2	3	4
F = 1	68.00000	68.00000	28.00000	64.00000
2	97.00000	108.00000	104.00000	80.00000
3	220.00000	244.00000	156.00000	212.00000
4	264.00000	264.00000	264.00000	264.00000

G = 2 S = 9

T =	1	2	3	4
F = 1	32.00000	88.00000	24.00000	32.00000
2	81.00000	60.00000	120.00000	64.00000
3	176.00000	228.00000	116.00000	172.00000
4	224.00000	224.00000	224.00000	224.00000

MEANS FOR STRESSED VOWELS

GRAND MEAN 104.85833

CELL AND MARGINAL MEANS

G =	1	2
	113.53333	96.18333

F =	1	2	3	4	5
	126.6944	98.6666	121.8194	95.7777	81.3333

	S =	1	2	3	4	5
G =	1	99.20	126.400	91.650	127.600	114.25000
	2	94.65	88.450	91.050	79.850	107.20000

	S =	6	7	8	9
G =	1	135.45000	131.00000	98.95000	97.30000
	2	113.80000	88.25000	111.20000	91.20000

	F =	1	2	3	4	5
G =	1	135.388	103.888	134.9444	103.6666	89.7777
	2	118.000	93.444	108.6944	87.8888	72.8888

G = 1

	F =	1	2	3	4	5
S =	1	138.00	91.00	100.00	91.00	76.00
	2	138.00	116.00	148.00	126.00	104.00
	3	107.00	104.00	113.25	82.00	52.00
	4	159.00	107.00	152.00	112.00	108.00
	5	119.00	109.00	145.25	122.00	76.00
	6	194.00	112.00	153.25	114.00	104.00
	7	130.00	126.00	168.00	119.00	112.00
	8	113.00	93.00	118.75	78.00	92.00
	9	120.50	77.00	116.00	89.00	84.00

G = 2

	F =	1	2	3	4	5
S =	1	104.00	81.00	125.250	87.00	76.00
	2	113.00	74.00	97.250	82.00	76.00
	3	121.00	81.00	105.250	68.00	80.00
	4	103.00	73.00	81.250	82.00	60.00
	5	122.00	115.00	116.000	103.00	80.00
	6	142.00	130.00	104.000	117.00	76.00
	7	105.00	82.00	113.250	73.00	68.00
	8	130.00	111.00	144.000	95.00	76.00
	9	122.00	94.00	92.000	84.00	64.00

G = 1 S = 1

T =	1	2	3	4

F = 1	136.00000	96.00000	224.00000	96.00000
2	64.00000	132.00000	60.00000	108.00000
3	100.00000	84.00000	136.00000	80.00000
4	160.00000	40.00000	60.00000	104.00000
5	76.00000	76.00000	76.00000	76.00000

G = 1 S = 2

T =	1	2	3	4
F = 1	176.00000	100.00000	156.00000	120.00000
2	136.00000	132.00000	76.00000	120.00000
3	148.00000	92.00000	236.00000	116.00000
4	224.00000	68.00000	72.00000	140.00000
5	104.00000	104.00000	104.00000	104.00000

G = 1 S = 3

T =	1	2	3	4
F = 1	80.00000	80.00000	120.00000	148.00000
2	152.00000	120.00000	52.00000	92.00000
3	113.00000	100.00000	120.00000	120.00000
4	160.00000	52.00000	44.00000	72.00000
5	52.00000	52.00000	52.00000	52.00000

G = 1 S = 4

T =	1	2	3	4
F = 1	192.00000	160.00000	140.00000	144.00000
2	128.00000	136.00000	64.00000	100.00000
3	152.00000	164.00000	148.00000	144.00000
4	228.00000	52.00000	76.00000	92.00000
5	108.00000	108.00000	108.00000	108.00000

G = 1 S = 5

T =	1	2	3	4
F = 1	136.00000	104.00000	156.00000	80.00000
2	112.00000	140.00000	84.00000	100.00000
3	145.00000	140.00000	220.00000	76.00000
4	212.00000	72.00000	72.00000	132.00000
5	76.00000	76.00000	76.00000	76.00000

G = 1 S = 6

T =	1	2	3	4
F = 1	196.00000	280.00000	184.00000	116.00000
2	124.00000	152.00000	60.00000	112.00000
3	153.00000	128.00000	220.00000	112.00000
4	212.00000	60.00000	56.00000	128.00000
5	104.00000	104.00000	104.00000	104.00000

G = 1 S = 7

T =	1	2	3	4
F = 1	172.00000	116.00000	112.00000	120.00000
2	152.00000	152.00000	76.00000	124.00000
3	168.00000	168.00000	212.00000	124.00000
4	228.00000	52.00000	56.00000	140.00000
5	112.00000	112.00000	112.00000	112.00000

G = 1 S = 8

	T = 1	2	3	4
F = 1	108.00000	100.00000	124.00000	120.00000
2	112.00000	108.00000	72.00000	80.00000
3	119.00000	148.00000	116.00000	92.00000
4	128.00000	32.00000	60.00000	92.00000
5	92.00000	92.00000	92.00000	92.00000

G = 1 S = 9

	T = 1	2	3	4
F = 1	136.00000	112.00000	120.00000	114.00000
2	100.00000	88.00000	60.00000	60.00000
3	116.00000	112.00000	136.00000	100.00000
4	160.00000	56.00000	60.00000	80.00000
5	84.00000	84.00000	84.00000	84.00000

G = 2 S = 1

	T = 1	2	3	4
F = 1	124.00000	84.00000	124.00000	84.00000
2	72.00000	96.00000	44.00000	112.00000
3	125.00000	160.00000	128.00000	88.00000
4	160.00000	32.00000	52.00000	104.00000
5	76.00000	76.00000	76.00000	76.00000

G = 2 S = 2

	T = 1	2	3	4
F = 1	124.00000	100.00000	128.00000	100.00000
2	72.00000	96.00000	48.00000	80.00000
3	97.00000	100.00000	136.00000	56.00000
4	140.00000	44.00000	60.00000	84.00000
5	76.00000	76.00000	76.00000	76.00000

G = 2 S = 3

	T = 1	2	3	4
F = 1	112.00000	112.00000	120.00000	140.00000
2	100.00000	96.00000	32.00000	96.00000
3	105.00000	88.00000	132.00000	96.00000
4	124.00000	28.00000	28.00000	92.00000
5	80.00000	80.00000	80.00000	80.00000

G = 2 S = 4

	T = 1	2	3	4
F = 1	92.00000	88.00000	108.00000	124.00000
2	72.00000	76.00000	40.00000	104.00000
3	81.00000	80.00000	64.00000	100.00000
4	168.00000	52.00000	32.00000	76.00000
5	60.00000	60.00000	60.00000	60.00000

G = 2 S = 5

	T = 1	2	3	4
F = 1	152.00000	88.00000	128.00000	120.00000
2	120.00000	156.00000	60.00000	124.00000
3	116.00000	148.00000	108.00000	92.00000
4	200.00000	48.00000	48.00000	116.00000

5	80.00000	80.00000	80.00000	80.00000

G = 2 S = 6

	T = 1	2	3	4
F = 1	144.00000	168.00000	132.00000	124.00000
2	144.00000	200.00000	64.00000	112.00000
3	104.00000	128.00000	104.00000	80.00000
4	156.00000	52.00000	60.00000	200.00000
5	76.00000	76.00000	76.00000	76.00000

G = 2 S = 7

	T = 1	2	3	4
F = 1	100.00000	124.00000	112.00000	84.00000
2	88.00000	100.00000	52.00000	88.00000
3	113.00000	156.00000	80.00000	104.00000
4	132.00000	44.00000	40.00000	76.00000
5	68.00000	68.00000	68.00000	68.00000

G = 2 S = 8

	T = 1	2	3	4
F = 1	128.00000	124.00000	160.00000	108.00000
2	104.00000	152.00000	68.00000	120.00000
3	144.00000	144.00000	156.00000	132.00000
4	172.00000	56.00000	44.00000	108.00000
5	76.00000	76.00000	76.00000	76.00000

G = 2 S = 9

	T = 1	2	3	4
F = 1	132.00000	112.00000	112.00000	132.00000
2	92.00000	108.00000	72.00000	104.00000
3	92.00000	96.00000	84.00000	96.00000
4	152.00000	32.00000	56.00000	96.00000
5	64.00000	64.00000	64.00000	64.00000

MEANS FOR INTERVOWEL INTERVAL

GRAND MEAN 308.09444

CELL AND MARGINAL MEANS

G =	1	2
	368.67222	247.51667

F =	1	2	3	4	5
	133.402	256.388	242.027	338.875	569.7777

	S = 1	2	3	4	5
G = 1	270.35	337.45	616.90	340.25	345.25000

	2	278.05	258.70	236.95	239.15	194.70000

	S =	6	7	8	9
G =	1	443.25000	375.05000	288.85000	300.70000
	2	237.35000	248.15000	274.45000	260.15000

	F =	1	2	3	4	5
G =	1	144.722	288.222	275.333	407.527	727.555
	2	122.083	224.555	208.722	270.222	412.000

G = 1

	F =	1	2	3	4	5
S =	1	132.00	269.00	206.75	344.000	400.000
	2	143.00	297.00	337.25	374.000	536.000
	3	121.00	311.00	294.50	642.000	1716.000
	4	165.00	232.00	245.25	343.000	716.000
	5	133.00	353.00	209.25	427.000	604.000
	6	169.00	327.00	401.25	607.000	712.000
	7	203.00	343.00	346.50	382.750	600.000
	8	125.00	231.00	233.25	343.000	512.000
	9	111.50	231.00	204.00	205.000	752.000

G = 2

	F =	1	2	3	4	5
S =	1	123.00	252.00	269.25	278.00	468.00
	2	125.00	229.00	218.50	281.00	440.00
	3	123.00	261.00	174.75	286.00	340.00
	4	119.00	200.00	186.75	226.00	464.00
	5	111.00	181.00	113.25	208.25	360.00
	6	139.00	226.00	215.75	306.00	300.00
	7	115.75	205.00	243.00	289.00	388.00
	8	131.00	253.00	237.25	283.00	468.00
	9	112.00	214.00	220.00	274.75	480.00

G = 1 S = 1

	T =	1	2	3	4
F =	1	152.00000	192.00000	96.00000	88.00000
	2	252.00000	404.00000	244.00000	176.00000
	3	207.00000	132.00000	248.00000	240.00000
	4	392.00000	308.00000	304.00000	372.00000
	5	400.00000	400.00000	400.00000	400.00000

G = 1 S = 2

	T =	1	2	3	4
F =	1	112.00000	144.00000	160.00000	156.00000
	2	364.00000	268.00000	228.00000	328.00000
	3	337.00000	500.00000	276.00000	236.00000
	4	508.00000	344.00000	388.00000	256.00000
	5	536.00000	536.00000	536.00000	536.00000

G = 1 S = 3

	T =	1	2	3	4
F =	1	108.00000	144.00000	172.00000	60.00000
	2	520.00000	192.00000	276.00000	256.00000

3	294.00000	184.00000	468.00000	232.00000
4	712.00000	1120.00000	388.00000	348.00000
5	1716.00000	1716.00000	1716.00000	1716.00000

G = 1 S = 4

F = \ T =	1	2	3	4
1	136.00000	184.00000	216.00000	124.00000
2	276.00000	88.00000	244.00000	320.00000
3	245.00000	172.00000	272.00000	292.00000
4	288.00000	456.00000	416.00000	212.00000
5	716.00000	716.00000	716.00000	716.00000

G = 1 S = 5

F = \ T =	1	2	3	4
1	84.00000	168.00000	160.00000	120.00000
2	376.00000	420.00000	272.00000	344.00000
3	209.00000	156.00000	272.00000	200.00000
4	516.00000	416.00000	552.00000	224.00000
5	604.00000	604.00000	604.00000	604.00000

G = 1 S = 6

F = \ T =	1	2	3	4
1	224.00000	120.00000	196.00000	136.00000
2	368.00000	204.00000	376.00000	360.00000
3	401.00000	308.00000	300.00000	596.00000
4	576.00000	400.00000	496.00000	956.00000
5	712.00000	712.00000	712.00000	712.00000

G = 1 S = 7

F = \ T =	1	2	3	4
1	184.00000	300.00000	192.00000	136.00000
2	476.00000	192.00000	352.00000	352.00000
3	346.00000	300.00000	376.00000	364.00000
4	404.00000	436.00000	399.00000	292.00000
5	600.00000	600.00000	600.00000	600.00000

G = 1 S = 8

F = \ T =	1	2	3	4
1	116.00000	168.00000	144.00000	72.00000
2	280.00000	172.00000	152.00000	320.00000
3	233.00000	240.00000	256.00000	204.00000
4	308.00000	368.00000	276.00000	420.00000
5	512.00000	512.00000	512.00000	512.00000

G = 1 S = 9

F = \ T =	1	2	3	4
1	100.00000	180.00000	88.00000	78.00000
2	224.00000	128.00000	288.00000	284.00000
3	204.00000	172.00000	240.00000	200.00000
4	184.00000	316.00000	200.00000	120.00000
5	752.00000	752.00000	752.00000	752.00000

G = 2 S = 1

T =	1	2	3	4

F = 1	100.00000	140.00000	144.00000	108.00000
2	272.00000	180.00000	252.00000	304.00000
3	269.00000	296.00000	260.00000	252.00000
4	248.00000	352.00000	340.00000	172.00000
5	468.00000	468.00000	468.00000	468.00000

G = 2 S = 2

T =	1	2	3	4
F = 1	76.00000	148.00000	124.00000	152.00000
2	228.00000	184.00000	300.00000	204.00000
3	218.00000	208.00000	232.00000	216.00000
4	268.00000	356.00000	308.00000	192.00000
5	440.00000	440.00000	440.00000	440.00000

G = 2 S = 3

T =	1	2	3	4
F = 1	84.00000	164.00000	168.00000	76.00000
2	288.00000	192.00000	256.00000	308.00000
3	175.00000	152.00000	176.00000	196.00000
4	260.00000	344.00000	360.00000	180.00000
5	340.00000	340.00000	340.00000	340.00000

G = 2 S = 4

T =	1	2	3	4
F = 1	104.00000	144.00000	132.00000	96.00000
2	208.00000	68.00000	256.00000	268.00000
3	187.00000	172.00000	208.00000	180.00000
4	168.00000	268.00000	300.00000	168.00000
5	464.00000	464.00000	464.00000	464.00000

G = 2 S = 5

T =	1	2	3	4
F = 1	56.00000	136.00000	156.00000	96.00000
2	152.00000	136.00000	212.00000	224.00000
3	113.00000	88.00000	100.00000	152.00000
4	217.00000	240.00000	268.00000	108.00000
5	360.00000	360.00000	360.00000	360.00000

G = 2 S = 6

T =	1	2	3	4
F = 1	116.00000	172.00000	172.00000	96.00000
2	208.00000	192.00000	232.00000	272.00000
3	216.00000	136.00000	228.00000	283.00000
4	260.00000	356.00000	396.00000	212.00000
5	300.00000	300.00000	300.00000	300.00000

G = 2 S = 7

T =	1	2	3	4
F = 1	87.00000	152.00000	120.00000	104.00000
2	200.00000	140.00000	236.00000	244.00000
3	243.00000	292.00000	224.00000	213.00000
4	260.00000	304.00000	328.00000	264.00000
5	388.00000	388.00000	388.00000	388.00000

G = 2 S = 8

	T =	1	2	3	4
F =	1	124.00000	176.00000	148.00000	76.00000
	2	260.00000	176.00000	340.00000	236.00000
	3	237.00000	168.00000	340.00000	204.00000
	4	260.00000	296.00000	328.00000	248.00000
	5	468.00000	468.00000	468.00000	468.00000

G = 2 S = 9

	T =	1	2	3	4
F =	1	72.00000	140.00000	136.00000	100.00000
	2	264.00000	96.00000	248.00000	248.00000
	3	220.00000	160.00000	292.00000	208.00000
	4	240.00000	271.00000	356.00000	232.00000
	5	480.00000	480.00000	480.00000	480.00000

MEANS FOR RUSS FOR FIVE NORMALS

	F2	F3	F4	F5	F6
SV	94	87	85	80	76
1USV	74	65	58	52	64
TUSV	74	145	225	285	315
IVI	205	285	395	470	640
ISI	373	517	705	835	1031